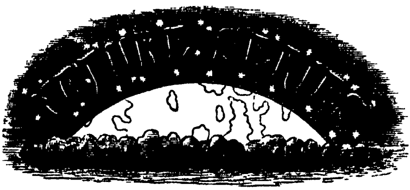
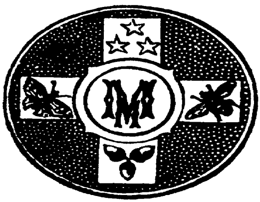


SEEING AND THINKING



NATURE SERIES

SEEING AND THINKING

BY THE LATE

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PREFATORY NOTE.

THESE LECTURES were delivered by Professor CLIFFORD at the Town Hall, Shoreditch. The Diagrams introduced are due to the kindness of Professor MICHAEL FOSTER, F.R.S, the shorthand reporter's notes of the lectures not being accompanied by any diagrams.

CONTENTS.

SEEING AND THINKING.

THE EYE AND THE BRAIN.

LADIES and GENTLEMEN,—I suppose we can all of us remember at a very early time having undergone some such catechism as this—'What is it that you walk with?' to which we should reply, 'Our legs.' 'What is it that you hit with?' and we should reply, 'Our arms.' Or, 'What is it that you eat and speak with?' and we should reply, 'Our mouths.' There are two questions analogous to those to which similar answers would very likely be given. If we were asked, 'What is it that you see with?' we should reply at once, 'Our eyes.' If we were asked a much more difficult question, 'What is it that you think with?' we might give two answers, according to what had been told us about it. We might say, 'We think with our brains,' and that would be an answer analogous to the others that we had given. Or we might say, 'We think with our minds,' and that would be quite a different answer from all the rest.

Now the answers that we should naturally give to the last two questions, viz. that we see with our eyes, and that we think either with our brains or our minds, are practically correct. Either of them is right enough for practical purposes, but neither is perfectly correct; and it is in order to show you what the more correct answer is which further knowledge enables us to give, that I want to explain to you to-night something about the mechanism of the brain and the mechanism by which it is connected with the eye. When we have considered this subject completely, we shall find out, I think, that it is not quite correct to say that we see with our eyes, and in the same way that it does not quite accurately represent the facts to say that we think with our brains or even with our minds.

Suppose that you see a person's hand resting upon the table at tea-time, and that you take a hot spoon out of your tea-cup and put it without any warning upon that person's hand, you will find that the hand will jump as soon as the spoon touches it. In the same way, if you suddenly tread upon a person's toe, you will find that the foot by a convulsive movement gets out of the way. A similar fact to that is this, that if you suddenly touch a frog which does not expect to be touched, the frog will jump and get out of the way. But there is this

difference between the two classes of facts: When you touch the frog and the frog jumps, the connection between the frog and the touch is all in the frog—there is nothing outside of the frog which makes him jump. But when you put a hot spoon upon a person's hand, and the hand suddenly jumps away, is that all in the hand? Or when you tread upon a man's corn and he suddenly withdraws his foot, is that all in the foot? No, it is not—we know for certain that it is not. If you were to cut in two a little white thread which runs up the arm from the hand, you would find that, however hot the spoon was which you applied, the hand would not jump. In the same way, if you cut in two a white thread which runs up the leg, you might tread upon my corns as much as you liked and I should not pull my foot away. It follows from these facts, that the connection between the hot spoon and the jumping of the hand and the connection between the treading upon the corn and the motion of the foot are not all in the hand or in the foot, but that there is something else wanted in order to make them complete.

What is the something else? It appears that a message has to be sent away from the hand or the foot to some other part of the body, and another message has to come back before a con-

nection can be established between the hot spoon touching the hand and making it jump, or the tread touching the foot and making that jump.

Let us consider an analogous case. Suppose a house of business in London has a branch house at Manchester, and the branch house is going to buy goods for the whole firm, but has been instructed not to buy goods without the consent of the principals in London. Somebody comes with goods to sell to the branch house, and after a little time the branch house buys the goods. Between these two incidents a communication has taken place between the branch house in the country and the central establishment in London. This communication may be of two kinds. The branch house may have sent up a letter and may have got a letter back through the post-office, or they may have sent a telegraph message and have got a telegraph reply back. Now these are two exceedingly different things; they are both messages which are transmitted from one point to another, and an answering message is sent back in both cases, but the nature of the message is very different. In the one case a material substance, a letter, carrying in itself the message, travels from one place to the other, and a similar material substance is sent back; but in the case of the telegraph message we have very strong reason

to believe that there is no material substance which goes from one place to the other and no material substance which comes back. In that case the transmission is not exactly but is very nearly like that which I could produce in a rope stretched from one end of the room to the other. If I give it a shake, that shake travels along the string, but there is no transmission of any material substance from one end of it to the other.

Which of those two ways of transmitting a message is used to transmit a message from the hand to some other part of my body, which we shall find afterwards is my brain, with the effect of making my hand jump when the hot spoon is put upon it? The mode of transmission is more like the electric telegraph than it is like the letter—there is no material substance travelling up from my hand to my brain, and back again from my brain to my hand; but there is a certain state of motion which travels along, although it is not exactly the same thing as that which travels along the electric telegraph wire.

How do we know that? We know it by a very simple circumstance. The nerve thread—the white thread which goes from my hand to my brain—is capable of transmitting a message which is exactly the same as the message trans-

mitted by the electric telegraph wire. If you put one end of the nerve in connection with one pole of a battery and the other end in connection with the other, an electric current will be sent along the nerve, which will be exactly like the current which is sent along the telegraph wire. The nerve is capable of transmitting a message, but we happen to know that that is not the sort of message which is carried along the nerve when the hot spoon is put upon the hand and the hand jumps. We know it in this way: If you cut open my arm so as to expose the nerve, and tie a string round it, you will find that the nervous message which my arm naturally sends along when in health will not go along, in consequence of the string being tied round my arm. It has the same effect as the arm being paralysed. Tying a tight string round my arm is just the same as cutting the nerve. The electric current, however, will go just as well when the nerve is tied up as when it is not tied up; therefore the message which goes along the nerve is not the same as that which goes along the telegraph wire, and yet it is something very like it.

Now we can tell with a great deal more accuracy than this what it is exactly that goes along the nerve. I have arranged here a series of ordi-

nary playing cards, bent in the middle to make them stand upon the table, and you observe that they fall instantly in succession on being touched. When a message has been sent along a nerve, there is something else which happens, and that is that the blood which is always running round the nerve in exceedingly minute pipes, or vessels, as they are called, contrives to build the nerve up again as it was before. Now what happens when the hot spoon is put against your hand? The hot spoon gives a little jerk to the ends of certain white threads which come out very near to your skin all over it. You will observe that something travels along, but it is not any material substance which travels along; it is the same state of falling which travels along the cards from one end to the other, because each of them gives the other a little hit as it falls over.

This model which I have here, and which represents the nerve, consists not of one continuous thing like a string, but of a number of separate cards; and that is one important respect in which it resembles those white threads which we call 'nerves.' Those nerves are made up of a number of separate things which are, as nearly as may be, alike—they are made up of what are called 'molecules.' Molecules are exceedingly small portions of matter which can

go about by themselves. Whenever any kind of matter is reduced into a gaseous state ; if water is boiled and made to go into steam, the molecules of which water is composed go mostly in straight lines, but turn each other round when they come in contact with each other, precisely as people dancing 'Sir Roger de Coverley' dance up in straight lines and turn each other when they meet in the middle. In the nervous substance these molecules remain as nearly as possible in the same condition—they, no doubt, oscillate a good deal on each side of their positions, but still they do not travel round about each other as the molecules of air do in this room. We have, however, very strong reason to believe that the nervous substance is made up of those molecules laid along in a row; and that all those molecules are little machines which are almost exactly alike.

How do we know that they are little machines? There are two things which show that the separate parts which make up the nervous thread are to be regarded as little machines—because they have two properties which are common to all the machines that we know of. One of those properties is known as the Law of the Conservation of Energy. Those are long words, but they just mean that you cannot get any more work out of a

machine than is in it. Suppose, for example, you lift a weight up to a certain distance; you have done a certain amount of work, which is reckoned in foot pounds—that is to say, you must measure up the distance you have lifted the weight in feet, and measure the weight in pounds, and multiply the two numbers together, and that will give you the amount of work you have done. Now, this energy you have used will always do the same amount of work again. Suppose I take an elastic strap and pull it apart; in pulling that apart I have done a certain amount of work, and in doing that I might have lifted a weight up a certain distance, and in pulling itself together again the strap would have lifted up that same weight. In order to make a steam-engine work you have to supply it with a certain amount of coal; that coal represents work which the sun has done in past ages, and the heat can be brought out by the fire in burning the coal, and a certain portion of it can be brought out to work the engine—only a certain amount, though, because there is a certain portion of it which must necessarily be wasted in working the engine. But it is only by the imperfection of the machinery that we lose any portion of the power; and the rule applies to all cases where molecules exist and where we can test it. Wherever we can test cases where

molecules are concerned we find the rule hold good—that they work just the same as other machines, never doing anything for nothing, and always doing exactly as much as they are paid to do. An example of this is found in the heating of water: you do a certain amount of work when you heat the water; a certain amount of work can be got out of the water by means of the steam-engine, and whatever is not got out of it can be accounted for in consequence of the imperfection of the engine. That is one of the reasons why we are right in saying that those small particles of which the nerve fibre is built up are little machines.

But there is another reason. There is a very general law which applies to all machines whatever, and to all mechanical actions, and that is that the change in the motion of anything depends upon its position with relation to other things. If a body was moving by itself in the universe without anything else to disturb it, it would go on moving in that way without any change at all. Any change which takes place in the motion of that body implies that there is something else moving in the universe. Now there is a certain change taking place in the molecules, which shows that there is a change taking place in parts of them. These are motions of vibration, just like

the motions of vibration of a tuning fork when it is struck.

Those motions of vibration in the molecules give rise to what we call light and heat, which are actually the motions of something between the molecules and ourselves. By means of the phenomena of light and heat we are able to find out what is the exact character of the motion of vibration of the molecules, and we find that although every molecule has a great number of ways of vibrating, just as a plate of glass has a number of ways of vibrating according to the way in which it is struck with the violin bow, yet each of these vibrations taken separately follows a perfectly definite law, from which we can show that the change in its motion at any instant depends upon the relation of the molecules to one another. For those two reasons we have a right to consider that the molecules, the small parts of which matter is built up, are little machines.

I have taken up so much time upon this point because it seems to me an exceedingly important thing to show you that the nerve fibre, the little white thread which carries the message along, is not anything very different from the things we are accustomed to behold. It is only different from the steam-engine or from any string

of cards in being a little more complicated, and in being so very small that we cannot yet tell exactly what is its precise mode of working. You may say that it is not very satisfactory to know merely that the thing is a machine of some sort; why cannot you tell us what sort of machine it is? what shape it is, and how the different parts of it work upon each other? I only wish I could tell you; but we have all of us very great hopes that no very long time will elapse before we shall be able to tell you more about it, because it is the conviction of almost every physicist of the present day, that the next great step taken will be to show what is the constitution of a molecule; what is the shape of it; and how the parts of it act upon one another.

In the meantime, however, let us assume that this message which goes along our white nerve thread is merely the working of a piece of machinery which is started at one end and which goes on working towards the other end. And I want to make it a little clearer that there is an analogy between the falling of this pack of cards and what I may call the falling of the successive molecules in the nerves. In ordinary life we do speak of things falling into an easier situation when we do not mean exactly things falling to-

wards others. There are many cases which are analogous to the nerve structure; one is a train of gunpowder. Gunpowder is composed of various substances which supply materials for each other's burning, so that when you supply fire to it the substance which has to be burnt gets the gas which is to burn it, not from the air but from the gunpowder itself. Now, what happens when the gunpowder is burnt? It is simply that the different sorts of molecules fall into a position which is easier to themselves than the position in which they were at first; and you will see that the molecules falling into that easier position will travel along and set fire to the magazine.

Now we see that in the gunpowder we have different substances mixed together, but in nitro-glycerine there is a thing which happens very much like what happens in the nerve. The molecules of nitro-glycerine are all alike. When you shake the nitro-glycerine and make it explode, there is no formation of new molecules, but there is just a re-arrangement of the molecules, which cannot remain in the same position where they were, but make a gas. This gas requires a great deal of room to live in, and consequently there is an enormous expansion produced when you shake the nitro-glycerine and make it explode. In this case, as

well as in the other, what really happens is that there is a large number of very small machines which fall into an easier position, and which help each other to fall into that easier position, and then when they have so helped each other they cause the explosion. That is what causes the falling of my row of cards—that each card in falling enables itself to fall into an easier position, and that motion is passed on from card to card. This explanation of the transmission of motion in the nerve fibre was given very clearly by Mr. Herbert Spencer, but the best physical evidence that I know of it is contained in certain experiments of Du Bois-Reymond, but the experiments form a very long story, and I do not propose to trouble you with them. It is quite sufficient to assume that the nature of the message which is transmitted along a nerve is a falling into an easier position of the successive molecules of the nerve, which enable each other to fall as they drop themselves.

I spoke just now of the nerve as a 'string of molecules.' It is not exactly a 'string.' The nerve consists of a sheath containing within it a fatty substance, and inside of that is the 'axis cylinder' of the nerve fibre itself, which is an exceedingly minute thing. About 5,000 or 10,000, or even more, could lie in one inch. Now a molecule is a small thing. You

know that the molecules of water are so small that from 200 to 2,000 millions of them could lie in a centimètre, which is about $\frac{1}{3}$ of an inch; therefore from 600 to 6,000 millions can lie in an inch. Now you will see that, supposing the nerve fibre to be composed of molecules of water, there would be from 120,000 to 1,200,000 of them in the breadth of it; but we have every reason to suppose that the molecules of which the nerve fibre is composed are very much larger than the molecules of water. If we suppose that those molecules are five or six times larger than that, we reduce the number of molecules which are in the nerve fibre, but still we do not reduce it to anything much less than from 20,000 to 200,000. So that instead of taking a string of cards as we have taken them here, we should take from 20,000 to 200,000 such strings, and set them side by side, and suppose that each one started off the other.

Now, there is this fact settled about the transmission of motion along the nerve fibres, that it can go either way; and this brings us to another class of nerve fibres, which exist in the body, and which apparently contradict that fact. When the hot spoon touches the hand, the hand starts. There are certain nerve fibres whose ends come out in my skin, which are very sensitive, and which can be set off falling down by the

slightest possible touch. The message passes up my arm along these very delicate white threads, goes up the back of the neck, and comes down again, not upon the same threads, but upon an entirely different series of threads. The threads which carry up the message are called *sensory* fibres, because they carry up the sensation. They are nerves used by the senses to convey the message to the brain. The nerves which bring the message back, and tell my hand to jump out of the way of the spoon, are called *motor* fibres, because they tell my hand to move.

The discovery that there were two entirely different sets of nerves in the body, some carrying messages *to* the centre of the body and some *from* it, was the discovery of Sir Charles Bell. You will see that this is apparently a contradiction of the fact I mentioned to you last, that the nerve which carries the message goes up to the central office, and never comes down from the central office to the end of the fibre. On the other hand, the message which comes along the motor nerve always travels in *one* direction; it comes *down* from what I am calling the central office to the end of the fibre, where it is embodied in muscle and makes the muscle move. But, on the other hand, it has been found that if you take a sensory

nerve and excite it at the central office, it will come *down* the other way. And, again, on the other hand, if you were to get at the head of the motor nerve and excite it at the central office it would send it *up*, but it would not send it down upon the opposite sensory nerve.

The reason why messages do not go forward and backward upon the same nerve is not that the nerves are incapable of carrying such messages, but that the ends of them are not so arranged as to deliver them when they are carried. You know that a telegraph message is carried with enormous rapidity; that the delay which takes place in the delivery of the message is merely caused by the time which it takes to produce the different signals corresponding to the various words or letters, and the time it takes to carry the paper at the end to the person to whom the message is addressed. The actual time it takes to send a signal along the telegraph wire is nothing at all, practically. It is a certain time, but it is minute; whereas the time taken by the transmission of the nerve message is not at all minute; that is to say, in the case of a nerve message in our own bodies, the distance being very short, the time is very small, but the velocity is not that exceedingly great velocity which we find in other cases,

as in that of light, for example, which travels nearly 200,000 miles a second, while the nerve message only travels about 50 to 60 miles an hour, which is about 90 feet a second.

This question of the velocity along the nerve was solved by Professor Helmholtz in an exceedingly interesting way. Professor Helmholtz is an exceedingly interesting man. In the first place, he began by studying physiology, dissecting the eye and the ear, and finding out how they acted, and what was their precise constitution; but he found that it was impossible to study the proper action of the eye and the ear without studying also the nature of light and sound, which led him to the study of physics. He had already become one of the most accomplished physiologists of this century when he commenced the study of physics, and he is now one of the greatest physicists of this century. He then found it was impossible to study physics without knowing mathematics; and accordingly he took to studying mathematics, and he is now one of the most accomplished mathematicians of this century. That a man who begins by studying one subject, and that so concrete a subject as physiology, which is a study which requires you to be constantly in actual contact with facts, should proceed from that to a study like physics, which is

a thing which you must do in your head mostly, and from that should go on to a still more abstract study, namely, mathematics, which you can do entirely in your head, having heard the facts from somebody else; that a man should do all this, and with such success, is, I say, a most remarkable thing. It was in that way that Professor Helmholtz was enabled to understand at what rate the motion was transmitted.

I can explain it in this way. There is a certain nerve in a frog's leg which moves a particular muscle, and there is an analogous nerve which moves a corresponding muscle in the human body. This nerve in the frog can be cut out, with the muscle still attached to it, and it is found that for a long time both nerve and muscle remain alive, their condition indeed remaining very much the same as when they were in the body. During this time the nerve can be excited by sending the electric fluid along it, and the excitement in the nerve causes the muscle to contract endways and sideways. You can feel the muscle doing that by taking hold of your biceps and bending your arm; you will then feel the muscle swell up; the muscle gets shorter, and at the same time it swells out sideways. That is produced by a message coming down the nerve,

your nerve spreading itself out in innumerable small ramifications into the muscle.

Now this can be observed just as well when the nerve and the muscle have been cut from the frog as when they are in the frog. Professor Helmholtz cut off a portion of this nerve, and he found it was workable by the electric fluid. He fastened a bristle against the side of the muscle and attached it to a cylinder of glass. When the nerve was set at work the point of the bristle was found to describe a curve upon the cylinder, and that curve could be afterwards unwrapped. Now Professor Helmholtz observed that there was a certain time before the muscle began to act; it then pulled the point of the bristle up and then left it; the point went at first slanting downwards; it then went up hill and then went down again. He then excited the nerve a little farther up, and he found a curve described which was longer than before. Now this was obviously because the nerve took a longer time to vibrate, and that *difference in time could be measured with great accuracy, and the distance along the nerve could be measured with great accuracy*, and it could in that way be ascertained what was the length of time the nervous discharge took in going from one point to another; and it was found out that if that current had gone on for a

whole second, it would have gone on about 90 feet, which you will find is from 60 to 90 miles an hour.

Now I must ask you to suppose that I have done something with this row of cards which I have not actually done. You must imagine that I have got a house of cards built at this end of the table, and that it is so built and made so sensitive of the transmission of a blow from one card to another, that when you touch a card at one end you would knock the house down at the other. You can then conceive that if there were a number of other strings of cards proceeding from the end of this house they would all be set falling. That house of cards represents what is called the 'grey matter' of the nervous system. This grey matter is a number of cells or corpuscles, as they are called, that is to say, little round things which have a skin and a nucleus, but of whose exact constitution very little is known, excepting that they are just like nerve substance itself. They are capable of falling into an easier position whenever a little disturbance is given to them; they are even more unstable than the matter of the nervous fibre.

Now when a message is sent from the extremity of the body up to some central office and back again—the central office that we speak of means just a collection of this grey matter—a lot of houses

of cards, so to speak, all put up together, are set falling down as soon as this message comes to them, and may in turn set a number of other houses falling down which represent the motor nerves. That is a thing very analogous to what really happens when we send a telegraph message to a small town in the neighbourhood of a big town—the grey matter standing in the place of the central office where messages are received and where corresponding messages are sent out. But there is this difference, that the message which is sent out in the case of the large telegraph office is exactly the message which was received, which is not the case with the nerves. When the hot spoon touches my hand, a message goes up the spinal cord and comes back again. The message does not excite the nerves which come back to my hand, but excites certain muscles which make my hand move, and this is a different thing from the message which goes up.

How is this produced? We must suppose that there are two central offices; any message which we can actually produce in the body is really a very complex message. It is started upon a great number of the ends of the small nerve filaments, and each of those carries its message quite separately away into the big cords. All those nerves are kept quite separate in the cords by having a

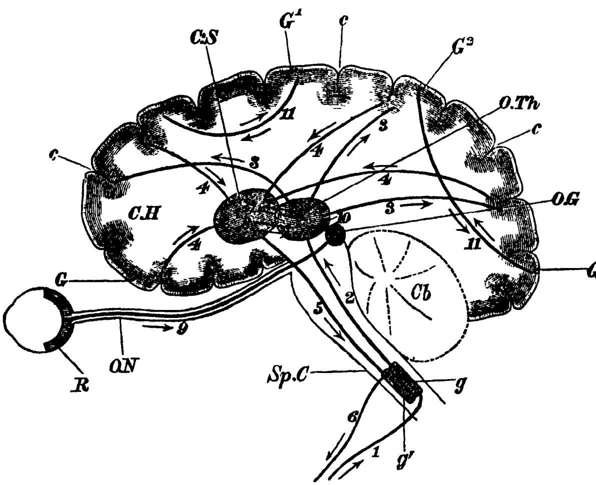
fatty matter around them, and that very complicated message arrives without losing any part of it, and without any disturbance in any part of it, into the collection of houses of cards, which represents our grey matter. That collection of messages arrives in the first central office, and constitutes altogether one great message ; and for this reason, you know, if you send a message by telegraph, for example, you have two different motions, for all the different letters are produced by the combination of two signals, either of which can turn right or left. But a nerve can only carry one kind of message—it can tell at the end that it has been disturbed at the beginning. In order to carry a complex message, therefore, such as 'A hot spoon has been laid upon my hand,' a great many nerves have to be employed. You can see by a complication of signals it would be possible to convey a message like that. One thread can only say, 'I have been disturbed' ; but a number would say, 'We have all been disturbed' ; and when this compound message comes into the office what the grey matter does is to combine it altogether.

How it does this we do not know ; but it combines the messages sent up along a number of threads into a message which it conveys to the central office. That process is called co-ordina-

tion, which means keeping the company in order. The messages being united and sent on as one message to the next central office, this next central office does another thing—the one message which is sent to it is, 'Pull a certain muscle or number of muscles'; but in order to keep those muscles in order it has got to send out a large number of messages, each of which goes to a particular place in each particular muscle; and it just un-co-ordinates the message which has been just co-ordinated at the previous central office, so as to produce this motion of the muscle. Now, if you feel down your back you will find a number of knobs. What you feel there is the spine, which is made up of a great number of different bones, and each of those small bones has got a hole in it, so that when they are all put one upon another, it is like a lot of pill boxes one upon another, each of which has a hole in the top of it and a hole in the bottom, so that you can put a thread through all of them. The thread which goes through those holes is called the spinal marrow—it is made up of white nerve threads and fatty matter. When any message is sent up from my foot, as when you tread upon my toe, that message goes in at the back between two of these bones into the spinal cord; the nerve threads there end in a certain mass of grey matter

(fig. 1, *g*) ; a 'knot' it is called, or 'ganglion.' Close to that there is another ganglion (fig. 1, *g'*), so close that physiologists differ about the precise difference between them ; but close to that, as I say, there is another ganglion, from which messages go out from a hole in front between the same two

FIG. 1.



bones, and those messages which come down from the front (fig. 1, 6) go down to my toe and tell it to get out of the way.

The office of those two ganglions in my spinal cord is that one co-ordinates a number of sensory

messages coming in from behind, and transfers them, so co-ordinated, to the other knot. The other knot sends the corresponding messages to a number of muscles, telling them to move in the right way, so that you see that every pair of nerves in the spinal cord may be regarded as a small brain, because what our brain does upon the whole is to receive the messages and send out the answers, teaching each part how to move. We may in the first place, therefore, regard our brains as a number of small cords which go all the way down our back. Now, when we come up to the brain itself upon the top, there is something more to be said. In the first place, we have the two knots which are difficult to distinguish in the spinal cord; perfectly distinct things. One is called the *optic thalamus* (fig. 1, *O.Th.*) —'thalamus' being the Latin word for 'couch'— the other is called the *corpus striatum* (fig. 1, *C.S.*) These are two masses quite separate from each other; the sensory nerves (fig. 1, 2) go to the one, and the motor nerves (fig. 1, 5), which go to the spinal cord, come from the other. The nerves which go to the spinal cord may be divided into those which go to the spinal cord and end there; those which begin at the spinal cord and go away; those which come from the brain down the spinal cord, and those which come back

from the spinal cord to the brain. We are certain that there are some which go to the spinal cord and end there, and others which begin at the spinal cord and come away, because if the spinal cord is injured—if a man has broken his back—you can still produce convulsive motions of the legs by pricking them, or affecting them in some other way. Messages will still be carried from the foot to the spinal cord when it is not possible to send them up to the brain. That which is called the 'reflex action' was discovered by Dr. Marshall Hall. But there are others which run right up to the brain and come down again. The first office of the brain, therefore, is just to receive messages in the *optic thalami*—to co-ordinate them there—to transmit them to the *corpora striata*, and the *corpora striata* tell them what to do with them.

But that is not all. I have made a sort of train here which will tell you what this other structure is [exhibiting a rough model of the nervous brain structure].

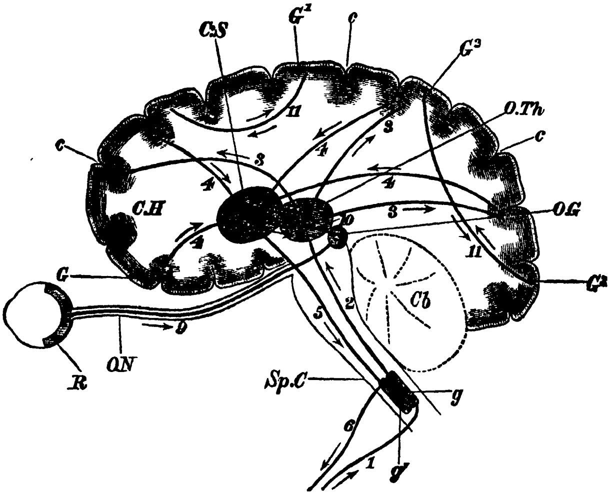
Messages, when they come up from all parts of the body into this portion of the grey matter, which is at the base of the brain, having been carried across are sent to other parts of the body, and that is how you perform complicated actions without having your choice asked about them. If a cat

comes suddenly round a corner and you jump out of the way, you perform an exceedingly complicated series of motions in consequence of the complicated sensations. It is not like the case where a pressure upon the foot makes the foot get out of the way, but there is a complicated sense of vision and feeling, and from that you deduce an exceedingly complicated series of actions to get out of the way. There is a number of motions you have to perform—you have to keep yourself up to the balance and to get out of the way. You do that without being asked to do it, but as the result of a variety of complications.

The largest portion of the brain is that which I have drawn on this diagram. I have here a section of the brain, and you will notice that it is all crinkled round in what are called convolutions (fig. 1, *G.*) It is doubled in upon itself round the grey matter. In order to get a clearer notion of what is called the cerebral hemisphere—for it is in two parts, there being a furrow which divides them into two parts, and 'cerebral' meaning 'brain'—we must suppose that it is much thicker than it appears here—it looks thicker because it is doubled upon itself a great many times—that grey matter which is doubled upon itself (fig. 1, *G.*) to form the hemispheres occupying 300 square feet, which is an

enormous area to think of as doubled up inside a man's skull. So that here we have a great piece of thin matter, that is to say, a great town of card-houses, any one of which is exceedingly sensitive, and any one of which might be knocked down in

FIG. 1.



a moment and built up again by the blood. Each of these things is connected by white threads (fig. 1, 3, 4) with the 'streaked bodies' (the *corpora striata*) and the *optic thalami*. Now suppose a message comes in from any part of your body to the *optic thalamus*, that message goes up the nerves (3) to

the cerebral hemisphere; then the messages are interchanged by means of the white threads which you see (fig. 1, 11) going across from one part of the cerebral hemisphere to the other (there is a great interchange of messages from all parts of the cerebral hemispheres), and then those messages come down (fig. 1, 4) from all parts to the 'streaked body' and are sent out along the muscles.

When you have a choice what you will do and what you will not do, there is a much more complicated thing which happens—that is to say, a message has gone up to the cerebral hemisphere, and has been dealt with by the sending of those messages along the nerves, and then messages sent along the 'streaked bodies' to the nerves telling them to perform the requisite motions. In the brain there is more than there is in the two knots of any part of the spinal cord. It is quite true that we have the two knots, but besides this structure we have the cerebral mass of grey matter which is put inside of your skull, and that may be consulted by one of the two knots before it sends on its message to the others. If the message is sent on straight—merely translated into shorthand and sent on—then you have a case which is just like the automatic action of the spinal cords, except in the length of it. The spinal cord may act automatically, and you do not

know it because the message is sent up to one of those small brains in the spine, and has been sent down, but not been sent up to the big brain, so that you do not know it. If it has only gone to the small knot, and then been sent back again, you do a thing, but you have no choice about it. It is a thing which you do instinctively without any choice, without thinking 'I shall be run over if I do not get out of the way.' But if you have time, and you consider, 'Shall I be able to get across?' and then you come to the conclusion that you will be able to get across, there is a much longer interval which elapses between your sensation of the cab coming towards you and your determination of what you will do. You have to make a calculation, and that calculation is made in the brain by means of the white threads which go across; so that there are two distinct ways in which a connection may be established between the incoming message from the end of your body, and the outgoing message which tells certain muscles to move. I have here a section model of a man's head, which will show clearly the exact position of the structures we have been considering.

Now there is just one kind of message which goes in to the brain which I want to consider particularly, because it tells us more about the mes-

sage from the outer world than any other—that is, the kind of message which comes in from the eye. We are going to consider that in our next lecture, but I will just say in what way it is that the message comes in from the eye and is carried to the brain. I have here a diagram (fig. 4) of a section of the eye, which shows what the shape of it is ; but it shows (which is the most important thing) that at the back of it there is a skin of grey matter which is called the *retina*, *Rt.*, which is connected with an innumerable number of nerve-fibres which go away into this great bundle of fibres which is called the optic nerve, *O.N.*, and that optic nerve goes down to the knot of grey matter called the optic ganglion, which is connected with the *optic thalami*. This diagram (fig. 2) shows the optic nerves going away into connection with the brain. Now the nature of the message to be transmitted is this :—In the front of the eye there is a lens (fig. 4, *L.*)—that is to say, a transparent body which is shaped like a burning glass, so that as the light falls upon it, it is made to converge to a point upon the other side. This light which falls upon the burning glass makes upon this skin, *Rt.*, a picture of the thing outside, which is just like a picture upon the ground glass of the photographer's camera ; and when the light falls upon this sheet of grey matter, which is at the back of the eye, that picture

disturbs it. The card-houses which are at the back of the eye are so exceedingly fragile that they fall down at once, and the nerves carry that message away into the brain, and that is one of the particular messages which is carried away from the brain, and which is acted upon by the brain in the form of sending that message by the nerves which move certain muscles.

Before concluding, I might say that I have chosen this subject in order to awaken an interest in the greatest possible number of other subjects. As we go on we shall see that this particular subject that we have been treating of is a sort of Clapham Junction of all the sciences in regard of the number of trains of thought which converge at this point, and which go out from it. In the first place we have a connection with physiology; in the next place we have a connection with physics, as you will see on our next meeting, when we shall have to consider some of the properties of light; and we have a connection with mechanics by means of the mechanical explanation of those actions which go on within us; and we have connection with a subject far more difficult than any of these, namely, the subject of consciousness—what it is that we see, whether we see rightly, and how it is that we think. And also, it may be observed,

as this is a sort of junction of all the lines of the sciences, that there are more trains of thought which go off the line just at this point than at any other.

I should like to recommend you to read, as bearing upon these subjects, Michael Foster's 'Primer of Philosophy,' which is published by Macmillan, and costs 1*s.* It does not go in any detail into the particular subject of which we have to treat, but it will teach you just as much physiology as is wanted before you begin the study of the subject.

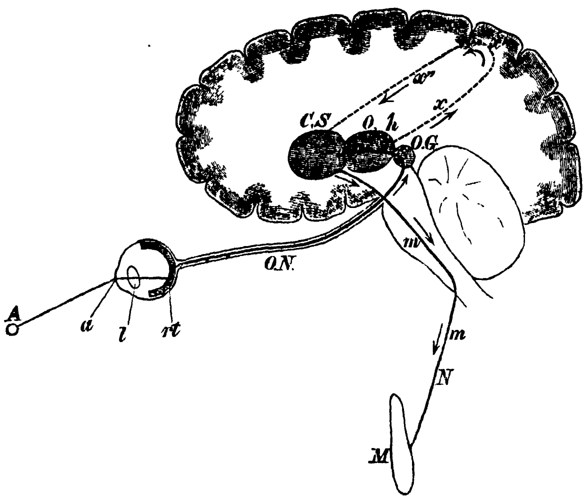
THE EYE AND SEEING.

LAST Thursday we endeavoured to consider what were the means provided in our bodies of sending messages about from one part to another, and we found that these means were to ordinary sight very fine white threads, which are called nerves; and we found that the sort of message which was sent along a nerve was a piece of mechanical excitation which was something like the falling down of the nerve from one position into an easier position; and we illustrated that by means of a pack of cards, which was bent and made thereby to stand up in such a way that if the last card was hit, it made all the row fall down one after another, by propagating the disturbance given to one end of the row on to the other end. Now to-day we shall have to consider what is the special connection between one particular part of the body, namely, the eye, and another particular part of the body, the brain; which enables us, as we say in ordinary

language, to see with our eyes, or—as I think we shall find that we can say with a little more exactness—to see with a part of our brain.

I will first of all tell you the whole story quite shortly, and then I will go over the several steps

FIG. 2.



of it separately. Here (fig. 2) is a picture which, slightly modified, is one of Dr. Carpenter's. Light comes from an outside object; it passes in through the outer coat of the eye at *a*; then it passes through a lens, *l*, that makes it converge upon a point in the retina behind, *rt*; from that retina a

message is carried away by the optic nerve, *O.N.*, to the optic ganglion, *O.G.*, thence to the optic thalamus, *O.Th.*, thence to the *corpus striatum*, *C.S.*, thence along the direction of the line *m* to the spinal cord, and so it goes away down to the muscles at *M*.

That is the story in short, but there are a great many points of this which, you will see at once, want much more explanation. In the first place, how is it that a message is taken from things outside of the eye to the eye? Next, how is it that this message, being taken from external things to the outer coat of the eye, is made to produce by the constitution of the eye a picture of the external things at the back of the eye? And in the next place, how is it that a message stating what is the character of this picture gives us the sensation which we call sight?

First of all about the message which comes from external things to the eye. It was thought a very long time ago (it is very difficult indeed to conceive how people should have thought so) that when you saw anything, a message went from your eye to the thing that you saw. But it is very easy to convince yourself that the message does not go in that way, but comes from the thing you see to your eye. But what sort of message is this? It

turns out from physical investigation that the message is just of the nature of a wave which is sent along a cord when we shake it, or of the nature of those waves which spread out over the surface of water when you throw a stone into it.

You know, when you throw a stone into a pool of water, that waves go out in circles from the place where the stone has fallen in, and travel away, still keeping the circular form, till they come against the edge of the pool. The only difference between those waves of water and the waves of light is that, whilst the waves of water go out on the surface of the water and make circles, the waves of light go out in space in all directions and make spheres. When one of these gas lamps is burning there is a tremendous disturbance set up by numerous atoms of carbon getting united each with two atoms of oxygen and then shaking about violently. They shake about and transfer that shake to something which is all over this room and all through space, which is called the *luminiferous ether*, because it carries such shaking as takes place when a thing is burnt, and the atoms fall into a more convenient position in consequence, from place to place; and that *shake* when carried by the luminiferous ether is what we call *light*.

In order to carry a shake such as this it is ne-

cessary to suppose that the luminiferous ether is not a fluid like water, but that it is a solid, something like a piece of jelly. It is an exceedingly difficult thing to conceive how there should be a separate substance filling all space, and filling up all the interstices between different molecules of bodies, and which yet leaves us able to walk about in the midst of it as we do. But that is the truth. There is a solid substance not made up of the same molecules as ordinary matter, but which is such that these molecules move about in it, and when they shake they produce waves of disturbance which spread round in this solid substance in all directions, and these waves are what we call light.

Now we can form a very clear conception of what the physical nature of these waves is. First of all, suppose I have a rope tied to the edge of this platform and also to the lowest part of the gallery at the opposite end of the room, and that I give this rope a shake. I shall send that shake all along the rope, making it take the figure of a corkscrew, and that wave will travel along the rope to the other end. Next suppose that instead of one rope there is a great screen at this end, and from a great number of points on that screen ropes go away to different points at the other end of the room, and then I take the whole screen and give it

a circular shake. That will send a corkscrew wave along every one of these ropes at once, and all these waves will go along in the shape of a great vertical plane. It is as if a *sheet of corkscrew motion* were actually travelling along from one end of the room to the other; so that the shape of that wave is a *plane*—that is to say, the parts of all those distinct ropes which are at any instant in a state of vibration are all in one vertical plane parallel to the two ends of the room. That plane containing all the disturbance of the separate pieces of rope is what is called a wave-front. Now the motion of the luminiferous ether is something like that. We can represent it again in this way: Supposing the whole of this room to be filled up with sheets of paper parallel to this end of the room, and then that these sheets of paper are made to turn round and round upon one another in this way (*describing it*) so as to produce the figure of a corkscrew; the travelling along of that corkscrew figure will be just like the motion of a wave of light.

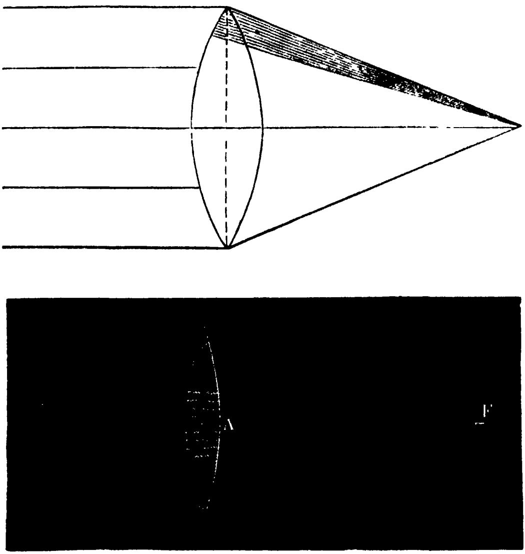
Now if a wave of light goes along in a plane like that, how is it that we speak of rays of light? The rays of light just correspond to my series of ropes that I suppose to go from one end of the room to the other. The ray of light is just a small part of the wave considered as travelling along in

a direction perpendicular to the plane of the wave. You see that the plane of this wave which I have been describing would be parallel to the opposite end of the room, but the line along which this travels is the line of the length of the room, and that is perpendicular to the plane.

We have now to consider what is the reason that rays of light can be made by means of a lens to converge into one point when they were not converging before. And that is what actually happens. A piece of glass shaped like this will take rays of light which are coming all parallel, and will bend them round, so that they go and meet in one point, or very nearly so. Let us now enquire what is the nature of this bending—why it is that a piece of glass is able to bend the rays of light so as to bring them together when they were going along parallel. That again is illustrated by this upper diagram. I have drawn here a line which represents the front of a ray of light coming on a surface of glass. This represents what the lower part of the wave would be if the glass did not interfere with it. But the glass interferes with it in this way: it makes it go slower. A wave of light going in air or in a vacuum goes at nearly 200,000 miles a second; but when it goes into glass it only goes at about two-thirds of that rate. Now, the

effect of that is that instead of this wave or this disturbance having got as far as the farther surface of the glass, it has only got as far as the dotted line; and the result is if the face of the wave is turned

FIG. 3.



round in that way, then in the same way the direction in which the wave is going is also bent round in that way. Exactly the same thing would happen if there was a line of soldiers marching all abreast in the direction of an arrow, and, having been walking

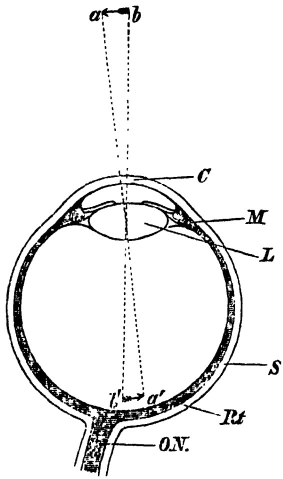
on perfectly smooth ground, they came upon a triangular wedge of ground which is more difficult, and which has stones about it, and consequently were obliged to walk more slowly. You would find then that when the line of march came out of the division between those two grounds, the front would be changed, because the soldiers would hang back a little, not going so fast as before. So then the reason why a transparent substance like glass will bend round the rays of light which impinge upon them is that light goes more slowly in those substances than it does in air.

You can thus see in a general way why it is that a lens-shaped piece of glass should bend round rays which come all in the same direction, and make them converge to a single point, or nearly so; because it is not easy to see that the lens should be able to make them converge accurately to one point; and as a matter of fact, no ordinary lens that is made for a telescope, or for any other optical instrument, does make the rays converge exactly to a point—there is always a little error—and in order to make the rays converge exactly to a point, the lens would have to be made of a very peculiar shape, which is exceedingly difficult to construct in practice; but for the ordinary purposes of optical instruments it is quite sufficient to

make the surfaces of the lens spherical, that is to say, like the surface of a ball.

It was supposed that the lens which is contained in the eye, and which you see in this figure, did not possess that defect; because it was known very early that the surfaces of this lens were not exactly spherical, and it was supposed, because of the deviation of the surfaces from a spherical shape, that the lens of the eye was more correct than an ordinary lens, and therefore made the rays converge to a point. But the fact is, it is not more correct, but less correct than ordinary lenses. Here (fig. 4) is a diagram of an eye which is supposed to be cut through by a perpendicular plane going from front to back. You see that outside of all is a case, an outer coating *S.*, and that this eye, instead of having the true shape of a ball, bulges out, and there is a horny substance called the cornea, *C.*, which protects the front part of the eye. Then, just behind that there is a lens called the

FIG. 4.



crystalline lens, *L.*, and that is tied on to the eye by muscles, *M.*, which go round it in a ring and tie it to the edge of the eye where the eye joins on to the cornea. When there is an object outside the eye, and light comes to it from this object, the light which comes from any particular point of the object, if it is far enough away, may be regarded as coming all in the same direction; and consequently I have only drawn one line to represent the pencil of light that comes from the point of the arrow *a*. The rays would be made to come very nearly to a point just here, *a'*, upon the retina or curtain, *Rt.*, which lies at the back of the eye. There would, therefore, be produced in this point a picture of one end of the arrow, and similarly at this point, *b'*, of the retina a picture of the other end, *b*, of the arrow; so, altogether along this part of the retina, there would be made a curved picture of the arrow upside down, because you see the rays of light cross themselves in passing through the lens of the eye.

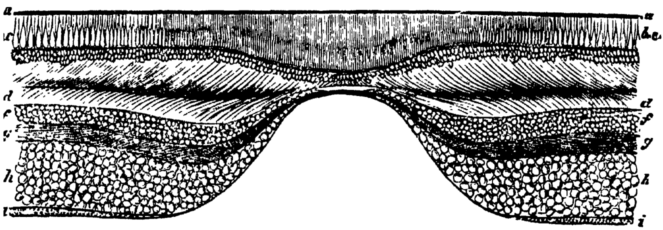
This picture is exactly like the picture which is produced upon the ground glass of a photographer's camera; and, in fact, a photographer's camera is merely an eye made of glass with a sensitive plate put instead of a retina. In the camera, you know, there is a lens which is put in the front, and then

behind that lens is put either the piece of ground glass, if you are going to look at the picture first, or else the sensitive plate when you are going to take it. Upon this piece of ground glass or the sensitive plate a picture is produced, which resembles the object outside, but it is upside down, and if you look into the camera while somebody else is sitting, you will see that picture upside down. Now, that picture produced on the lens of the camera is produced in exactly the same way as a picture of an external object is produced upon the retina. The result is that we have different points of this screen illuminated by means of the lens of the eye by light which has come from outside. From all the points outside light comes to this lens, and the light coming from each point is made to converge to a single point upon the retina.

Now we must go on to consider what is the character of this screen upon which the picture is allowed to fall. The picture put here represents a very little bit of the retina. There is a spot of the retina there, which is called the yellow spot, and in the middle of that a depression called the central pit, and the picture which is drawn here is merely a magnified section of the retina just at that place, after it has been hardened in alcohol. The things which you see at the right hand of this picture, *b e*,

are called the *rods* and *cones* of the retina. There are about 1,200,000 of them just at this central pit. It is those rods that receive the light. All this other part of the retina, *d f g h i*, is occupied, not in receiving the light, but in transmitting the message from the rods and cones which lie at the back of the retina. Just in front of these rods and cones there are little round things called corpuscles,

FIG. 5.



which belong to the rods and cones, and which are excited when these are excited. Coming away from these, there are a great number of exceedingly fine nerve fibres, and they go away connecting different parts of the retina together, so that after running over the retina in various directions, they finally come away in the optic nerve.

So, then, just at this point which is called the central pit, the machinery for carrying away the message when it has come is much thinner than it is anywhere else. All these fine pipes thin away

just as they come to this spot and disappear. The magnitude of the spot may be judged from this, that if you hold your forefinger out as far as you can and look with one eye at the finger-nail, it is just that little space that covers the central pit in the retina, and when you are looking straight at a thing, then the light from the thing falls on this central pit, but only so large a thing can be seen at once as is as big as your finger-nail held as far away as possible. But then, what happens to this light that falls here upon these rods? We must remember again what the light is. The light is a disturbance of the luminiferous ether—that wonderful solid body which fills all space—which is transmitted to it from molecules which are shaking very violently. That disturbance, when it comes upon other molecules, which are not particularly steady, which are liable to be upset, shakes them violently and may upset them; and that is just what happens to this grey matter composing the rods and cones, and this matter falls into an easier position as soon as it is upset. So that the effect of this message coming from something outside, and falling on a particular spot of the retina, is to upset the grey matter which is there, and to make it fall into an easier position. When that grey matter, which we represent by a house of

cards, is upset, it transfers that upset to the white threads that end in it, and the fall is transmitted along those white threads exactly as it is along our row of cards. The message is then taken along these white threads away out of the eye. These fine fibres carry away the message along the optic nerve.

Let us now consider what is the use of that lens which is put in front of the eye. Why is it necessary to take the light which diverges from a point like the arrow-head, and to make it converge again at another point? It is in order that all the messages which come from that point, and which are spreading out in all directions, may be taken to a particular point on the retina. You see if there were no lens there, every part of the retina would receive messages from every part of the space outside, and that would be very inconvenient, because it would be impossible to separate them from one another. But instead of that, one part of my retina now receives a message from the hour hand of the clock, and that particular point has only to transmit that particular message to the central office in my brain. And similarly every one of those rods is connected with one particular white fibre, and when one of those rods receives a message, it sends it away along its own fibre, and

that message is not interfered with by any other message, but goes along all by itself, like a message along the cable telegraph wire, to the brain.

The use of the lens is to take a great many of the messages which come from an external point, which spread out over the whole space of the pupil of my eye, and to send all those messages to a particular point of the retina, and in proportion as it does that with accuracy, in that proportion it is a good instrument. The lens has to be like the lens of an optical instrument first of all in that particular, in making all the light converge together to a point. If it were quite perfect it would be perfectly transparent, it would have the same structure all through, and no fibrous structure, no pulling round, such as you see in a bad piece of glass, and it ought to get all the colours that come off any object, and to send all those colours together to the same point. If the lens were a perfect thing, it ought to operate upon all the colours alike, and to send an image of a red point to the retina with exactly the same accuracy as it sends the image of a blue point, and to send those images to the same place. A perfect instrument, or an instrument made by Mr. Browning, say as well as he could make it, would do those things very nearly indeed. There are several other points of perfection

which would be absolutely required in a good instrument made by an optician; but these points are all of them very *ill* represented in the eye.

Regarded as an optical instrument, the eye is a practical success so far as it is wanted, but certainly not beyond that. I will read you what Helmholtz says: 'Now, it is not too much to say that if an optician wanted to sell me an instrument which had all these defects, I should decline to take it off his hands on purely optical grounds.' You see it is very fortunate for us that for ordinary purposes these defects count for nothing. We can see quite as well as we want to do, notwithstanding these defects—that is, most of us can. The actual discovery of these defects has only been made of late years, and a great number of them have been discovered by mere accident; and if there were really reasons why we should want eyes as perfect, considered as optical instruments, as telescopes are, I have no doubt that in the course of generations we should gradually learn to grow eyes which would be perfect enough for the purpose for which we wanted them.

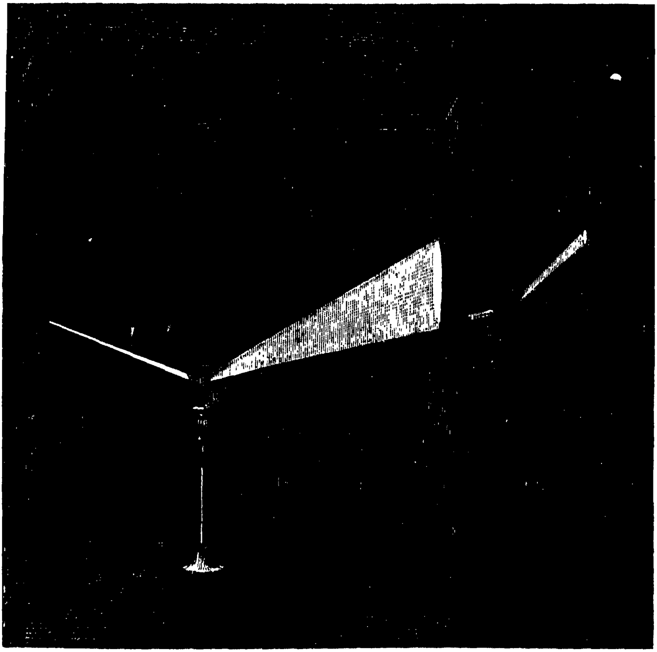
Now, we have so far accounted for the retina having a message to transmit to the brain, which says how much light there is at every point of it, and which therefore will say something about the

appearance of the object outside. We have accounted for a picture being produced on this retina, which is like a picture drawn in black and white, and the compound message taken away from the retina, goes and tells the brain how that picture is filled up; how much light there is at every point of the retina. But the things that we see are coloured things, and we have now to consider how it is that the retina can transmit to the brain a message saying that there is something coloured outside.

In the first place, let us consider how it is that the external thing can transmit a message to the retina, saying that it is *coloured.* It is found that the difference between that disturbance of the ether which makes red light, and that which makes blue light, is that the waves of red light are longer than the waves of blue light; and the various colours which are in the solar spectrum—that is to say, in the figure which can be produced by a prism held in the way of the sun's light—correspond to vibrations of the ether which are of different rates; but those colours are arranged all along in a series, and it is quite clear also that if that were the only difference in the light coming to the eye we should only have a single series of colours; we could arrange them all in a string; you would put the

colours having the longest waves at the bottom, and the shortest at the top, and the others could all be arranged in a series between those two, as the

Fig. 6.



ray coming from the left, which is white light, consisting of light of all colours, is spread out in a

long strip on the screen, with the red at the lower and the violet at the upper end.

But that is not the case. The colours we receive cannot be arranged in a single series, but they can be arranged upon the surface of a triangle; instead of forming a line, they form a surface. If we made a triangle, and put green at one point of the triangle, red at another, and violet at another, then we could arrange all the other colours on the inside of the triangle, according to the degrees in which these three colours were mixed up to form them. That was the discovery of Dr. Thomas Young, that all *sensations* of colour—that is to say, not colours outside the eye, not the waves that are transmitted along the luminiferous mediums, but all our sensations of colouring that we get—are made up of three sensations corresponding, it is now believed, to red, and green, and violet, and in the proportion in which these three sensations are mixed together, all the difference of the different colours is constituted.

Now, how is it that the retina is able to transmit a message, saying in what proportion these three different colours are mixed together? Well, we do not know how our own eyes do it, but we know how the eyes of birds and reptiles do it, and that is something towards it. Birds and reptiles

are things that appear very different from one another, but naturalists say that they are in very close relations, and that in fact a bird is only a little crocodile with feathers on. We are not surprised therefore to find that in the structure of their eyes there is a very remarkable similarity between them. Now, in the case of the eyes of birds and reptiles, certain of these little cones at the back of the retina have drops of oil at the end of them, and the drops of oil are of two kinds; some of them let in red light, and some of them let in violet colours. You know that a liquid may be so coloured as only to let through light of a certain kind, and the light it lets through is of the colour of the liquid; so if some of these cones have red drops of oil at the end, and others violet, you can see that those which have the red drops at the end will be most affected by the red light; the red drops of oil will stop all the light, in fact, except the red light, and when blue light falls on the eye, these particular nerves will not be excited, but when red light falls on the eye these particular nerves will be. And similarly for the other cones which have the violet; but those which have no drops of oil in front will be excited by all the colours. So we shall have three different kinds of cones, which will be excited differently, and according to the degree in which they are ex-

cited there will be different messages transmitted by the eye to the brain.

It is very important to notice what is meant by mixing two colours together in a certain proportion. If you take two *paints*, and mix them up together, you get a colour which is not that of either of the two paints. If, for example, you mix together blue and yellow, you will get green; but green is not the sum of the blue and yellow sensations: blue light and yellow light mixed together make a sort of dirty white, and the reason of that is that the blue paint cuts off a certain amount of the light, the yellow cuts off a certain amount of the light, and when you put them together they both cut off as much as they did before, and the only light you get is that which they both leave, and that is the green light. But when you mix the two *sensations* of colour together, then the blue light gives you a certain number of different coloured rays, and the yellow also, and the result is that you get light which is nearly made up of the white spectrum.

The way to see this is to take a piece of glass, and hold it at right angles to a sheet of paper upon which you have painted the two different colours. Supposing I have blue farthest away from me, and yellow nearest, and I fasten a piece of paper at right angles, I shall see the

blue through the glass and the yellow reflected, and the result of the two will be the result of an overlaying of the two paints, and will give me the sensation of a sort of dirty white. So that the message which every point of the retina takes away to the brain, tells it not only that there is so much light falling at that point of the retina, but it also says that this light which falls at that particular point is made up of three different colours, in certain proportions, and that message saying what is the proportion in which the three colours are mixed up in the light is taken away from the retina to the brain, which is the way in which the retina transmits to the brain a message saying that the image thrown upon it is a coloured one.

Now we said that it is only just through this central pit that we get a very distinct vision. The great majority of people do not find out that they can see with any other part of their eye at all. As a matter of fact you move your eyes round with enormous rapidity, so as to bring the central point, which is the most accurate of all, to bear upon successive points of the object. But with a little practice you can find out that it is possible to see with more of your eye than this central point. An easy way to prove that is by means of an electric spark. An electric spark may be made to

illuminate a thing almost instantaneously—that is, for only about the $\frac{4}{1000}$ part of a second. Now a large object like the eye cannot be moved in the $\frac{4}{1000}$ part of a second, and therefore you must see with other points of it than the central point, but you always find that there is one particular part of the object which you have seen accurately, and all the rest in a sort of hazy way, without accurate discrimination of the parts of it; and the reason of that is, first, that the cones at the back of the retina are packed very much more thickly together at the back of the central pit than they are a little way up, and secondly, that the connection between the cones and the optic nerve at other parts of the retina is very much thicker and the surface upon which the light falls is more delicate.

For ordinary sight, what we do is to move round our eyes so as to get the image of different parts of the picture thrown exactly upon this central spot, which is the most sensitive and the most accurate—and that is done by means of six muscles, which pull the eye round and turn it in its socket, and up and down—and in that way the range of the picture which we can see with the eye is enormously increased, and we know how that must be the case from the way in which you can limit the range of a horse by putting blinkers at the side.

Supposing you kept your eyes perfectly still (it is no good trying, because you cannot do it) and did not move them round, there would be only just one spot which you would be able to see clearly, and all the rest of the picture would be seen indistinctly. So that the range of vision is increased by these muscles which move the eye round, and also the moving of the eye round by these muscles has to be *guided* by the message which the eye sends to the brain. The message which goes away to the brain directs certain muscles. The optic nerve goes back to a knot called the optic ganglion, and I have shown you muscles which pull the eye round, and when the side of the eye sees something indistinctly which it wants to see distinctly it sends up a message, which tells the right muscle to pull the eye round, so that the image of that particular thing may be thrown upon the central pit.

We have got so far as this, that there are two eyes, and at the back of each of them there is a curved coloured picture of external objects, and this picture is continually altered by the eye being moved round, and different parts of the thing outside being represented. But that does not account for the sensations we have, because what I see at present is a *solid* room; I do not see a flat picture, but a number of solid things, and the question is,

how we are to account for that. That answers the question which would naturally have occurred to us, What is the good of having two eyes? because there is the same picture produced upon each of them, and we have just got a double message which is carried back to the brain. The two messages are as near as possible alike, and one does not tell any more than the other does—but still it does turn out that the very fact of our getting two pictures of the same object from our two eyes, gives us the impression of solidity instead of a flat picture—and that is proved by means of Sir Charles Wheatstone's invention of a stereoscope.

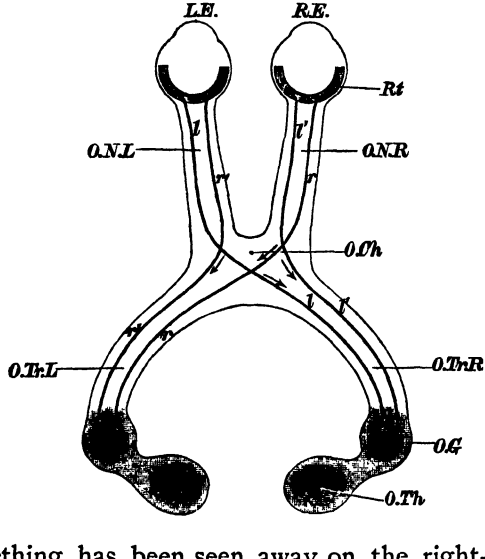
If you look at a picture that anybody has drawn, it never quite gives you the impression of a solid reality, and the reason is that the picture is flat and not a solid thing, but if you take two pictures, both drawn upon paper, both representing the same thing, but not quite alike, and then put them so that you see one of these pictures with one eye and the other with the other, then the very fact of your getting two slightly different pictures of the same thing with your two eyes makes you see the thing solid. Of course everybody has seen it in the stereoscope in its present form, which is Brewster's form of it; but the principle is that there are two different pictures, and the rays of

these two are made to converge by lenses put on the top of the stereoscope, so that we can conveniently see one with one eye and the other with the other—some people are able by squinting one eye to make the two pictures of a stereoscopic slide overlap, and then it steps out into a solid form—so that somehow or other the fact of our having two eyes and getting two different images from them is just what accounts for our getting a perception of solid things, thinking that we see solid things and that we see things at different distances from us.

But we still have to ask how it is possible that the mere fact of having two pictures nearly like one another, but not quite, will give us the impression of solid things. If you look at the picture on next page you see the optic nerve, *O.N.*, going away from each eye into the brain; here, *O.Ch.*, they join together, and then they separate again. Now at this point, *O.Ch.*, a very curious thing takes place; the nerves that go away here (fig. 7, *O.Tr.R.*) on the right-hand side are made up, not of these nerves alone, *O.N.R.*, but of some of these, *O.N.R.*, and of those, *O.N.L.*, and the nerves that go away here, *O.Tr.L.*, on the left are made up on the right-hand side of the two optic nerves, *r*, *r′*; something like the arrangement of the reins in driving a pair of horses. Just as the reins that come from each

horse are separate, so the two sets of nerves that come from each eye are separated here, *O.Ch.*; so that while the nerves which tell the brain that

FIG. 7.



something has been seen away on the right-hand side go to the left-hand side of the brain, the nerves which tell the brain that something has been seen on the left-hand side all go to the right-hand side. Now if we suppose that that arrangement is a sort of hint of what goes on in the individual nerve fibres, we shall find that something happens like this: that the two nerve fibres which go out from

corresponding points on the retinas—that is to say, two points which would be excited by the same object at the same time—go very close together in the brain; the ends of them are very near together. We know that the left-hand nerve fibres of one eye and of the other do go as a whole to the right hand of the brain. It seems right to guess from that that each particular nerve fibre goes and finds out its brother on the other side, and that they go to the same part of the brain.

We cannot explain it on the supposition that these two nerves unite together. That supposition has been made, but it will not explain the fact, because there are facts which have been established by Helmholtz, and which show that it is impossible to account for the sensation of solidity being carried along one particular nerve for every point of the solid. One would guess that it was not possible, because you would see that it would want so very much larger a number of nerves than those wanted for carrying a picture. If you have simply two sets of nerves, that also is an easier thing to carry about than a set of nerves which has one for each point of the solid marble. But there are some circumstances connected with vision in a stereoscope which show that this cannot be the case. One of them is: you know that surfaces

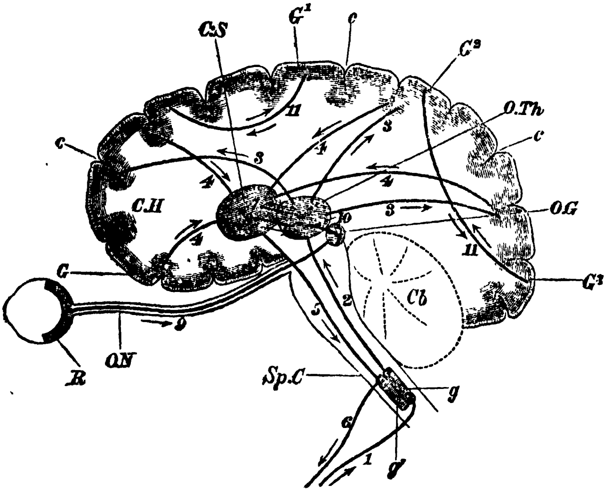
give an impression of what is called sheen—you can see that they are polished surfaces—and that is quite independent of colour. Now what is the reason of that? Polished things reflect light as well as scatter it. The ordinary light by which you see things is scattered light, but when a surface is polished it will reflect light regularly, very much in the same way that glass does, besides scattering it. But this reflection for a given piece of light only goes in a definite direction. For example, in one of those pillars I can see a sort of long image of each of the lights in the top of the hall, but that long image is in a different position in my two eyes; then my eyes seeing two different images of the reflected light very near together, conclude that there is something coming off the surface of the pillar which is not originated there; the reflected light goes in a different direction as to one of them from what it does in the other. The result is that when I see two images of reflected light coming off a body from different parts of it, I conclude that it is a polished body, and it has the appearance to me of a thing that is smooth. Now that cannot be represented in a picture; it is absolutely impossible. The only way in which painters can paint things so as to make them look polished, is to give them all the other appearances which go with polished

things, and therefore suggest that they are. But the stereoscope will give you the impression of a polished body at once; if the surface of a picture shown in a stereoscope is brighter in one of the pictures than it is in the other, then it gives you the impression of a polished substance.

If, then, the sensation of solidity cannot be produced by the joining together of these two nerves, how is it that we get it at all? We can only say that the two nerves come very close together in some place here in the optic ganglion: they do not actually join, but come to two little knots of grey matter near to one another, and excite those two, and corresponding to the excitement of that grey matter, going on at the same time, there is a sensation of sight in the brain: that is an absolutely different thing from the excitation of the grey matter; all we can say is that the two things happen together at the same time, and it so happens that the particular sensation which goes along with the simultaneous excitement of those two knots, at the end of fibres coming from similar points in the retina, is the sensation of solid objects. The reason why that sensation should give us all the other ideas connected with a solid object is quite easy to explain—that is, that having seen things which gave us this sensation we have gone to them

and felt them, and found them to be solid before; so that the sensation of having two pictures very much alike naturally suggests all those things we have done before with our feet and hands in walking round and feeling the solid things, and finding that they were solid.

FIG. 1.



Let us now consider what it is that becomes of this message that goes away to the brain from the two eyes. If you look at this picture again you will see that it is sent away (fig. 1, 9) first of all to this knot (fig. 1, *O.G.*) The optic nerve goes away

to these, and when a message is sent along the optic nerve of the eye, these masses of grey matter are excited—that is to say, upset just like a house of cards. So that the whole action is like this: there is a house of cards here, *R.*, and when this house is upset it sets all the cards falling there, *O.G.* A picture has been produced at the back of my eye of something which I am looking at, and a message goes away from every point of that picture to some particular point in the optic ganglion. There is not another picture produced in the optic ganglion, but there is a sign of a picture.

If I deliver a message to a telegraph clerk, and he proceeds to telegraph to somebody at the other station, the man at the other station does not hear words, but sees the signs of words—needles moving in a way arranged to stand for certain words. Just in the same way there is the actual picture produced at the back of the eye, but in the ganglion it is not a picture but a series of signs. Now, this is the important point: our sensation of sight corresponds, not to the picture which is at the back of the eye, and which fairly represents the external object, but it corresponds either to this excitement in the ganglion or to an excitement farther back still—we do not know which, but the only thing quite certain is that our sensation of seeing a thing does

not correspond to the picture made upon the retina, but to something which is the mere sign of that picture: it may be, as many people think, that our sensation of sight corresponds to the excitation or disturbance set up thereabouts (figs. 1 and 2, *O.Th.*) The message goes along here, sets up a disturbance in portions of grey matter lying at the back, and that disturbance is carried away by white threads (fig. 1, 3) to the cerebral hemisphere all round the outside of the brain. It is quite certain that that disturbance is carried along; but what it is that the sensation corresponds to nobody exactly knows.

We may have the sensation when the message comes here (figs. 1 and 2, *O.Th.*)—that is the opinion of the old anatomists, of Reil and of Dr. Carpenter, and a great number of inquirers at the present day; or we may have the sensation when the message comes up here (fig. 1, *G.*)—that is the opinion of Professor Huxley and of another lot of people. Those two suppositions may be made, either that the consciousness corresponds with the disturbance in this grey matter at the base of the brain, or else that it corresponds with the disturbance of the cerebral hemispheres at the top of the brain, and you may suppose whichever you like, but it does not make much difference to that very important conclusion we came to last—that is to say,

that the sensation of sight is *not at all like* the object which produces it. It is not like the object outside—the object outside is an arrow. The picture produced at the back of the retina is also an arrow, but the disturbance carried from that to the optic ganglion is not in the shape of an arrow, and it is not in colours. It is just *as if* there were signs of three different pictures transmitted into the brain, and then these were supposed to be coloured each of them with different colours, and then they were mixed together. It is quite certain, then, that whether the signs of the picture are produced by disturbances of the optic ganglion or are produced by disturbances farther back, the sensation which we get is no more like the object outside than the telegraphic message coming by the needle is like the words that may be transmitted to the messenger.

That is an exceedingly important conclusion to come to, and it leads us to some very important reflections. The world that we perceive—all the objects that we perceive during the whole of our lives—these are sensations that we get which correspond, in the sense that they go on at the same time with certain disturbances in the grey matter in our brain, or in the cerebral hemisphere at the top. All our sensations of feeling go along

at the same time with disturbances of grey matter, and if two sensations occur together it means that two pieces of grey matter are being disturbed together, and if a sensation which has occurred once is repeated, that the same pieces of grey matter which were disturbed once are disturbed again.

The question naturally presents itself to us, Is there anything outside of us which corresponds to our sensations?—that is to say, is the whole world simply Me, or is there something else? It is perfectly obvious that there is something else, but at the same time we can tell from the nature of the mechanism by means of which we see that that something else, which really is outside and which sends messages to us, is not like the messages we get; it differs from them just as much as the telegraphic message read off the needle differs from the signs used. There is no green or yellow or blue outside of us, but there is something which corresponds to it in a certain way, and which produces in our brain a disturbance which goes on at the same time as the sensation that we call green or yellow or blue.

That is one very important conclusion drawn from the theory of sensation. But besides the disturbance of the grey matter of the brain or of the

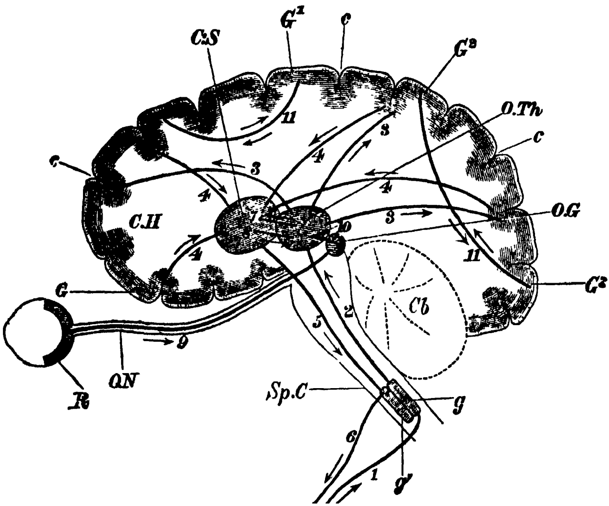
cerebral hemisphere, there is a reference back to the object that we see, so that we are enabled to get an exact picture of all the different parts of it, and a message has had to be taken from these ganglia to various muscles. If I am attempting to copy a picture on a piece of paper, a message is taken from the picture to my eye, and then away down to the muscles that move my hand. We have first a sensation of sight which corresponds to the message coming in from the eye, and then we have a sensation in certain cases of moving our muscles in consequence of that sensation.

As I said before, there are two different ways in which this can happen: the sensation which comes from the eye may immediately produce the movement of the muscle without any deliberation taking place between—that is the case of an action which is done, as we say, instinctively or automatically without the consultation or leave of the person who does the action; or a more complicated thing may take place: a message may come from the eye to here (fig. 1, *O.Th.*), and then it may be taken up (fig. 1, 3) to the cerebral hemisphere, and then it may come back again (fig. 1, 4, 5, 6); and then it may move the muscles, but in that case more time has been taken up, and a very much more important thing has been done—namely, we have

chosen what we shall do in consequence—and that is the difference between the two results.

In the first case, we appear to have done the thing without meaning it, but in the second case

Fig. 1.



we have that feeling which we have when we say, 'It was I who did it, and I did it deliberately.' Some of the muscles which are moved by messages going down to the brain are walls of those vessels which contain the arterial blood; there are certain nerves which go away to the brain which *pinch* the

blood vessels and send the blood to one set of nerves or the other. Now, this pinching of the blood vessels which directs the attention to a particular part of the body may take place in either of the two ways in which all other motions may take place. Our attention may be directed from one thing to another, as when we start and look round at anything which is presented to the sight of our eye without our leave being asked, as you will find your eye wandering over a pretty picture, or looking at something which is dangerous and approaching without your deliberately intending to move your eye. Or, on the other hand, the message going from your eye to the brain, which goes on again from the brain and orders these blood vessels to be pinched, and therefore your attention to be directed to a particular point, may go round by way of the cerebral hemisphere, and in that case your attention will have been directed by an effort of the will; and one of the most important properties of the human constitution is that we are able to direct our attention to particular things by an effort of the will—that is to say, that an effort arising in sensation, or the repetition of sensation, may go round by the top of the brain and pinch certain blood vessels which will send blood to particular nerves.

On the whole, therefore, I think you will agree with me that it is more correct to say that we see with a certain part of our brains than to say that we see with our eyes.

THE BRAIN AND THINKING.

IN the first lecture of this course I endeavoured to describe to you simply the mechanism of the nervous system. I told you then that the nervous system was made out of two parts; out of certain little white threads, which are called nerves; and out of certain little grey cells, which, when they occur together in knots or lumps, are called grey matter. We found that the use of the white threads was to carry along messages from one part to another; this being done by a purely mechanical process, in which the several parts of the white threads fell successively into an easier position than the position which they formerly held. We illustrated this by setting some cards up which had been built, and by knocking down the end one, which caused all the rest to fall in order; and we considered also that the lumps of grey matter to which the white threads go, taking these messages that run along the white threads, act exactly like a house of cards put at the end of one row of cards,

and that they fall down in that way and pass on a message (more or less complicated, in consequence of the complication of the grey matter) to other white threads, which again carry it away to the extremities of the body. Here, then, you see we described just one element out of which the nervous system is made. It is a string of white threads which run up to a lump of grey matter, generally in two pieces, and disturb that lump of grey matter in such a way that a message is sent down upon another string of white threads, either to the same part of the body from which it first came, or to some other part of the body. The whole action of that element of the nervous system, then, was to take a message from some extremity of the body up to some centre and back again, either to that extremity or to some other.

In the last lecture we considered how these elements could be put together into an exceedingly complex structure, whereby messages of an exceedingly complicated kind could be carried from the outside of the body into the brain, and then out again for the guidance of the muscles. That very complicated structure was the structure of the eye, of the optic nerve, of the optic ganglion, and of those white threads which run away from that part of the brain to the various muscles. We

showed in that way that a message coming from external things, could, by purely physical and mechanical means, again produce a picture at the back of the eye on that screen which is called the retina, and that from every point of this picture there was one individual message carried away into the brain on a white thread, still by a purely mechanical process; and a message coming into the brain was carried to a lump of grey matter and disturbed it, producing again a purely mechanical disturbance, and that from these messages were sent out to all parts of the body; that is to say, an exceedingly complicated return message was sent out from the central office, which caused the muscles to move, again by a purely mechanical process.

What we have to do to-day is to investigate how we can build up, out of this element of the action of the nervous system, the incoming of a message from without; the rearrangement of that message in a central office, and the sending out of another message, either to the same or to other parts; how out of that simple process we can build up that exceedingly complicated thing which we call human life.

But our considerations to-day will differ very greatly from those of the last two lectures. In both of these we were considering a series of purely me-

chanical processes, and it was only by the way that, in describing the action of the eye, we did, out of pure necessity, occasionally mention that there was connected with it a sensation of sight. But it is our business to-night in particular to take account of certain other facts which go along with and exist at the same time with those purely mechanical processes; and it so happens that in the far more complicated things which we have now to consider, it is those other facts which we know a great deal more about than we do about the mechanical processes which accompany them. But just at the beginning we shall have to consider the subject from the two sides at once.

Suppose, then, that you take a man's brain, and that you begin to dissect it under an exceedingly powerful microscope. If you had a microscope a great deal more powerful than any that we have now got—such a one, for example, as would magnify as many times again as the best microscopes now do magnify—you would find, upon looking at the nerves of a man's brain, that they were made up of individual structures of exceeding minuteness. But by a microscope so powerful as to be able to magnify not six or eight thousand times, but some fifty million times, you would find that you could see the nature of those structures. What you would

precisely see I cannot tell you, because nobody yet knows exactly how a molecule is made, but you would, by a microscope of that ideal power, be able to see a man's nerves actually made up of separate molecules, and when a message was transmitted along those nerves, you would see those molecules falling into new shapes in consequence of the transmission of a message, just as we saw the cards of one row falling down from the transmission of a little hit that was given at one end.

But however powerful a microscope you used, and however carefully you looked, it would be no use to expect to see the man *thinking*. All that you would see by the aid of that microscope, and with the most careful looking possible, would be just the motions of molecules, the motions of matter, the transmission of those motions along the course of the nerves, and the arrangement of those motions in the centres of grey matter; that is to say, the disturbances of other molecules, and then the transmission of the motions again outwards. You would see nothing more than the merely mechanical actions that we have described hitherto, and if you expected by the use of such a powerful microscope to see anything like thought, or sensation, or emotion, or will, you would be grievously disappointed. Still there is a great and a close correspondence

between these two things. At the time when the disturbance is carried by the light into the eye, and is transmitted along the optic nerve into the brain, and then is carried back from the brain to some of the muscles, at that very time something else goes on, and the man has a sensation of sight. All of you have a sensation of sight at this moment, and if you consider a little carefully what happens when you have a sensation of sight, you will, I think, with certainty arrive at these conclusions—that the sensation appears to come from outside of your mind. Of course it is entirely in your mind; any sensation you have got belongs to you, and is part of you, and is just a change of your consciousness, as people say; but still you have the impression that when you see anything fresh, the sight that comes into you does not arise out of your previous train of thought; it is not a mere continuation of what was going on in your mind before; and if it forms a part of any orderly succession of events in which each event is determined by those that have gone before, it seems pretty certain that that orderly succession of events is outside of you and not inside of you. It is not in the sequence of your previous thought that the origin of that sensation is to be sought. When I heard that train passing just this minute, the sound that came to me was not sug-

gested by the thoughts that had been going through my mind before, and it did not arise out of any orderly sequence, whereby each event of the sequence was determined by the previous one, but it seemed to me to come from something outside, to have its origin outside of me and to come into me.

At the other end of this phenomenon, if a *sensation* comes into your eye, or into your ear, it comes in that way at the same time that a *disturbance* comes into your eye, or into your ear. A sensation comes into your mind, and it gives rise, as soon as it does come into your mind, to a train of thought which is in you, and which does take place in an orderly sequence, whereby you can very often see the way in which the one of these follows the other. But then, suppose that it goes on to manifest itself in an action of some sort. You see an object, and you pick up the object. If we describe it entirely in terms of our sensations, if I see anything I say there is a sudden jump in my train of thought, indicating that something has come into my mind from without. Then the orderly sequence goes on, and from the sight of this thing I come to think of picking it up, and to want to pick it up. That is by an orderly sequence which we can observe, and which we can frequently predict, but then if, wanting to pick up this thing,

I make the exertion of picking it up, that is still a part of the orderly sequence of my thought; it follows from my wanting to pick it up just in the same way as any thought is suggested by any other thought, only from that point the sequence goes outside of me. There is then started an order of facts which is not only perceptible to *me*, as my thoughts are perceptible to me, but which is perceptible to *all other people* at once. When I pick up an object which I have been led to pick up from having seen it, a series of facts begins which you can see as well as I can, and that series of facts is correspondent to something which is outside of my mind, and that is your perception of them. If you see me pick up the thing with your perception of sight, that is a thing outside of the train of my thought.

We see, therefore, that in the case of this simple element, out of which we have to describe the whole action of the mind, there is something which comes into it from outside, which then goes on in the mind in a sequence which can be explained by the ordinary mental laws, and which then goes out of the mind again.

Now let us compare this with the corresponding physical facts. Instead of considering what goes on in a man's mind, how a sensation appears to

come into it from outside, how it is arranged in the mind itself, and how it then goes out of the mind in the form of an exertion, let us consider those physical facts which go on at the same time. Let us consider the disturbance that takes place in a man's brain. If we look at the picture we shall see that a very similar thing takes place there. A disturbance is produced in the eye which I have drawn to the right hand of the picture, and it runs along the line which you see running along to the brain, and which is the optic nerve. But while that message is running along the optic nerve the man has no sensation. We know that, because, if the eye is cut off by cutting through the optic nerve, you can still be made to have a sensation of sight by irritating the optic nerve. By irritating the stump of the optic nerve after it has been cut off a sensation of sight can be produced, and in a very simple way with your own eye. If, in a perfectly dark place, you press with your finger on the side of your eye, so as to compress the optic nerve, you will produce a sensation of sight, although there is no light there. It follows, therefore, that the sensation of sight, since it can exist without the eye at all, is not produced in the eye, but it must be somewhere beyond the end of the optic nerve.

Well, then, this disturbance is carried into the

brain from the eye; it comes into it from the outside. The disturbance which is set up in the optic ganglion, and in the rest of the brain by the incoming of that message, is not a simple consequence of the action of the brain which was taking place before it.

The brain was being disturbed, and it was transmitting messages from part to part of itself before that disturbance came in through the eye. But when that disturbance came in there was a sudden change in the action of the brain; a thing comes in from without, and upsets the order which was going on before, and introduces a new order of disturbances. But then, as soon as this disturbance from the eye is taken to the optic ganglion, it travels from it all over the various parts of the brain, so that the disturbance is carried forward; is rearranged in the brain itself; and that goes on according to the ordinary laws of action in the brain. It depends upon the shape of it, upon the way in which these white threads in its interior are arranged, that connect the different parts together; and so it is an orderly sequence of purely material events in the brain, which goes on in exactly the same way as the action of the brain goes on when no stimulus comes in from the eye—that is to say, the succession of events is just as if it had been

carried on in the brain itself, entirely without any stimulus from without.

But now suppose that besides this a message goes out from the brain to the muscles. Here we have some disturbance which has come into the brain from without, and which has re-arranged itself in the brain, going out again along certain muscles, and passing away from the brain altogether. It goes to those muscles and moves them, and that is all the brain has to do with it. You see here that the train of mental facts is precisely parallel to the train of physical facts. A sensation apparently comes into my mind from without; it is turned over in my mind; conclusions are drawn from it, and an action follows. A disturbance comes into my brain from without, a purely mechanical disturbance; it is turned over and reverberated in my brain, and then it is sent out from my brain again to a muscle to move it. But not only are these two orders of facts precisely similar in this respect, but we know that they take place at the same time; because when we have moved our muscles at the end of a sensation, we can see them move, and we know, therefore, that a motion of the muscle takes place after our exertion, which tells it to move.

Moreover, the material action which goes on in the body can be traced outside of the brain. We

can find the disturbance in the eye before it gets into the brain, and we can find the motion in the muscles after it has left the brain; but we know that the mental fact does not go along with these other facts, which are outside of the brain—it does not go along, as I said before, with the disturbance in the eye which takes place before it gets to the brain, and it does not go along with that disturbance which moves the muscles after it has gone out of the brain. We know that from some very curious things. If a man has had his leg cut off he will constantly complain of pains in his toes, although he has no toes in that leg to have pains in. But more than that, if he should try to move his toes he will then experience exactly the same feeling as if he had actually toes to move. Then what happens there? It shows that his consciousness only goes along with the disturbance to the near end of the motor nerves. The physical fact corresponding to that is that he sends the disturbance down from his brain, along certain motor nerves, telling his toes to move, and he knows that he has sent this message; but that is exactly what we feel whenever we try to move our toes. When we send a message down, which actually gets to them and tells them to move, so that the motion actually follows, then we have the feeling of having

sent that message out, and that is actually what a man can have when his toes are cut off; so that when we appear to feel in our toes that we are moving them, it is not really there that we feel it, because that feeling can take place without there being any toes at all. But we feel it somewhere in the near side of the end of that motor nerve—that is, we feel it somewhere or other in our brain.

You see, then, that our mental experiences are just what we should expect if we supposed that they had to go along parallel with the disturbances in our brains, and not with what takes place in other parts of our body—that is to say, we should only have a sensation of sight at the same time that a message is coming from the eye to the optic ganglion, or perhaps later, at least not before, and we should have a sensation of exertion before the message had actually got to the part which we want to move.

Now it is an exceedingly important thing, before we go any further, to notice how entirely separate these two classes of facts are, because for the rest of the time we are going to speak of them as always occurring together, and because of this exceedingly close connection between them. Along with every feeling that a man has (and feeling is a word which we use in the most general sense to mean either

thought, or emotion, or volition, or sensation of any kind; anything that goes on in the mind may generally be called a feeling), along with any feeling that a man has, he has at the same time a certain disturbance in his brain; but we must not confuse the two things together.

Many eminent men have been so much impressed with the exact correspondence between what goes on in our minds and what goes on in our brains, that they have mixed up the two things; and they have used expressions, such as to say that thought is a secretion, as if it were a really mechanical thing which was produced by the brain, or even a mechanical state of motion produced by the motion of the brain in the same way as other machines produce states of motion in other things. Or they have said that the mental force is correlated with the natural forces, meaning that it can be produced out of natural forces. These expressions belong to the view that mental facts, states of consciousness, that the whole subject of the mind of man is a subject dealing with a material thing like his body. The view which regards mental facts as just a part of a train of material facts is commonly called materialism.

It used to be a very hard word to fling at anybody to say that he was a materialist, but that sort

of word does not hurt so much now; and it is rather curious that a great many of those words which have been very hard in one generation, change sides and just hit the other people in the next. These eminent men have always been few in number, but we ought to speak of their opinions with the very greatest respect, though I think we shall find reason to say that we cannot even frame in thought any clear representation of their hypothesis—of the hypothesis, that is, that thought and mental facts generally are just a part of the train of material facts and can be mixed up with it. We have only got for ourselves to keep as close as we can to the actual facts of the case, remembering that there are two things which we can observe if we like—there is the train of material facts, the train of facts which is made up of nerves and muscles and white matter and grey matter, and there is the train of facts which is made up of sensation and thought and emotion, and of all those facts which we call mental facts. Just remember that we can observe these two, and that we can observe a parallelism between them, and then, I think, if we are careful enough, we shall get along very safely.

Now, then, we have to take, as a sort of brick out of which to build our house, this simple process,

the incoming of a message which is re-arranged and which is sent out again; and if we are careful to remember that there are two distinct classes of facts with which we are dealing, there will be no great harm in speaking of them together, and by the aid of the same words, because we shall find that in ordinary language the same words are used very often to speak of two sets of facts. The word 'impression,' as Mr. Bain pointed out, is one of them. We speak of an impression coming into our mind, but it would be equally right to say that the impression is produced upon the brain by some action outside which causes light to pass through the eye; and many other words are used in this way in either of two senses. But because this ambiguity has crept into our popular language, and because it is an exceedingly convenient thing to use them, that will not justify us in forgetting that when we do use these words we must take care to remember that there are really two classes of facts that we are speaking of together.

Out of that process we want to build up the more complicated action of the body and the mind. Let us first take a very simple connection between sensation and action; that is to say, suppose that at a time when we are hungry a piece of food is put into our mouth, and we instinctively

begin to go through the very complicated motion of chewing and swallowing it. This involves in the first place a previous state of the brain implied in saying that we are hungry, and it then involves a very complicated and combined message to be sent up from the tongue and from the muscles of the mouth, and then an exceedingly complicated message comes back to direct the motion of the tongue and the teeth in chewing and swallowing the food. Here the important things to notice are two. First of all, what are the messages which go in? And, secondly, what are the messages which go out? Here we have a case in which the thing is not quite so simple as that which we previously considered. There there was just one set of messages which went in from some one place, and a set of messages which went back in consequence of it, either to the same place or to some other; but here it is not sufficient that food should be put upon the tongue, and a message sent up from there to the brain in order to produce mastication. That instinctive movement of the mouth does not follow in cases where we have already had enough to eat. It is necessary that there should be beforehand that state of the mind, and that concomitant state of the brain, which we express by saying that we are hungry.

What is the meaning of that? It means that we get messages to our brain, not only from those organs which we call the five senses, from the eyes, and the ears, and the tongue, and the nose, and the skin generally, but that we also get messages from the inside of our bodies. The sensation of hunger is a message which is sent to me from my stomach, and from the rest of my body, to say that there is a want of nutriment. But this sensation of hunger differs from the other sensations in this. It suggests to me that I should get something to eat; but suppose I cannot carry it out in action—that it is not possible immediately for me to eat something—then it goes on and produces something which is called the appetite of hunger, which is an exceedingly unpleasant thing indeed, if it has gone on long enough. We have here, then, two more sets of messages which will differ from those that come in from the ordinary five senses. There are those which are true and direct sensations, which Mr. Lewes calls the stomachic sensations, such as those of hunger and thirst, and others which I need not enumerate here. These will serve for a type of them. Then, again, we have feelings which are called appetites, which impel us very strongly to do things which cannot be regarded as direct messages which come at that moment; they are continuous things,

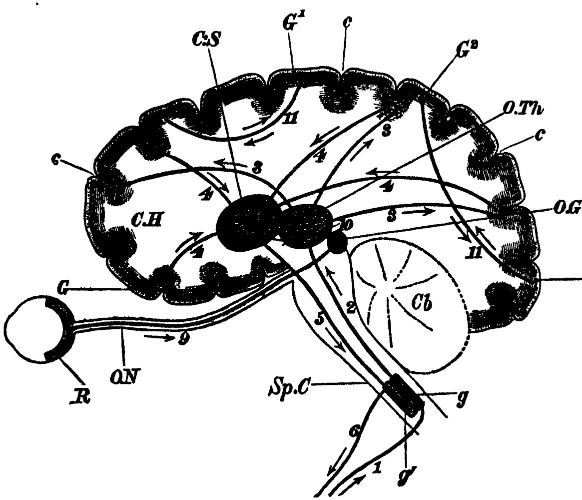
and we shall describe them most nearly by saying that they put us into a certain state in which sensations coming in from without will prompt us to certain actions, and without which they do not prompt us.

Now, I think that we shall get a very probable answer to the question what sort of state this is, if we consider that other point which I mentioned, namely—What are the sort of messages that go out? The outgoing nerves either go and move muscles, or they go and pinch the little tubes that carry the blood all about the body. These little tubes are called vessels or arteries, and they are carrying fresh blood to all parts of the body, and their office is to feed and reconstitute those parts of the body which have got wasted, and especially their office is to build up again the nerves that have got worn out. By sending enough blood around the nerves in any part of the body we can set up a disturbance among them; we get them into such a state that they are exceedingly irritable, and they will begin to fall down on the slightest provocation.

The corresponding fact in our mind to the sending of blood to a part of the body is what we call directing our attention to it. I said that there were two different ways in which a message might

come from the outside, and go to certain muscles—that it might either pass straight across the lower part of the brain, in which case the action is called instinctive, and in which case you move without being consulted, quite suddenly, without making a choice what you will do or what you will not do,

Fig. 1.



or else a message may come first to one of these little pieces of grey matter in the lower part of the picture, and then may go up to the top of the cerebral hemisphere, and then come back again to the other one, and then go on to the muscles. In

that case you have the sensation of having chosen to do what you do. Supposing that here (fig. 1, *O.Th.*) is one of the pieces of grey matter, and here (fig. 1, *C.S.*) is the other, and that a message is brought to this one, *O.Th.*, along a nerve (1. 2), it is carried out along the white threads, 3, to the upper part of the cerebral hemisphere, and then down again, 4, to this other piece of grey matter, *C.S.*, and so away to the muscles that are to be moved. Then you have the feeling that you have exercised a choice about that motion; that it is you that have done it, and that you have deliberated about it. That remark holds good just as much in the squeezing of the blood-vessels which direct your attention to a certain point, as it does of any other thing that is performed by the nerves. Your attention may be directed to any part of your body without your leave being asked, or it may be voluntarily directed by somebody pricking you with a pin, and in that case there is an instinctive pinching of these little vessels that you see about the brain, whereby the blood is carried to the nerves to tell you about the pain. You would not feel it nearly so strongly if it were not pricked.

Now, let us go back to the case where the stomach has sent up a message saying that it wants food. This message has produced the sen-

sation of hunger, and the incoming message would naturally have to go out again, and move something or other. But if you have no food at the time it is unable to go out and move your muscles, so as to make you eat food, which is the natural thing for it to do; it must, therefore, do something, and what it does is to direct your attention to the fact that you are hungry. That is what we call having an appetite, that is to say, the concomitant states of the mind and body in which we are more particularly ready to reply to certain suggestions from without. These are really states which again are produced in these grey centres, the centres of grey matter which connect together the sensations which are to come in, and the motions which are to follow, so that, in fact, the state of having an appetite means the state of being attentive to those connections whereby, when a piece of food is put into your mouth, you will naturally proceed to masticate and to swallow it.

Now let us suppose that we have a thing to do which is much more difficult than swallowing our food—let us suppose that we have to fight for it. When one animal has to fight another there is required an exceedingly complicated connection between sensation and action. To every motion of the antagonist the proper motion has to be op-

posed ; a certain guard has to be opposed, and this is required to take place with exceeding quickness, and also the motions of the muscles which follow upon this correspondence have to take place with a certain amount of violence. How is all this produced? It is produced by a state which we call an emotional state. The animal gets angry, and that state of being angry is a state of preparation for the transformation of sensation into action. When you are exceedingly angry, then your fighting propensities are called up and you want to fight, and if anybody annoys you you proceed to fight. That, again, is most probably a state of extreme attention to those particular connections which hold together the sensation of an enemy attacking you and the action of defence which you have to make against him.

The emotions, as you know, are very varied in their nature. There are those which are more simple, such as anger and love, the emotions which we speak of as pain and pleasure; but in all these cases there is a certain readiness or preparation for combining together sensations, and for finding out what actions ought to follow from them, and for performing those actions with a certain amount of intensity. The effect of pleasure, as Mr. Bain has pointed out, is best described by saying that it

causes us to persevere in the state in which we are, in the state in which we naturally want to persevere in, which directs attention to those particular connections which enable us to persevere in it. That is called the state of pleasure. On the other hand, if it is obviously a state which we want to get out of, and which directs attention to those particular connections which enable us to get out of it, that is naturally what we call a state of pain.

But from this point it is not at all easy to make out what is precisely the material counterpart of the mental facts. Nobody knows exactly what is the sort of action that goes on in the brain when we feel pleasure in any sensation; nobody knows precisely what happens when we feel angry. But it is rather curious, and it is worth noticing just at this point, that the one passage in the ancients where the problem of mental action as connected with bodily action is at all touched is just about this point. Aristotle, in his treatise *De Animâ*, speaks simply for the most part of the properties of organic beings—the properties of living things, what they do and how they contrive to do it. But in just one passage he says:—'Very often a thing takes place which has to be described by different men in different ways. Supposing a man is angry, he would be so described by the poet or the histo-

rian. Thus, the poet would say, this man is in a boiling rage—he is exceedingly angry, and is likely to do certain things; but the naturalist would say that there was a boiling up of the blood about his heart.' And he treats these as two sides of the same fact, pointing out that there were two distinct things to be observed, and showing how if the Greeks had only gone on in this way, they might have arrived at just the same point of science at which we have now arrived, a great number of centuries before this.

But it was not until the time of Descartes that people again began to consider the problem of consciousness in any sort of intelligent way. Of course we know that it was an entirely wrong thing to say that the physical counterpart of being angry was the boiling up of the blood about the heart. It was a mistake that the ancients made, that the motions in and about the heart were connected with the emotions and the passions, and that has run into our popular language. We speak of a person being good-hearted, or bad-hearted, and so on, but that, as you know, is an entire mistake. The mental facts go along with and parallel with disturbances taking place in the brain, and not in any other part of the body. But that remark of Aristotle's was an exceedingly acute one, as

showing what was the precise point of view which scientific men would take when they came to consider the problem of consciousness.

In all these cases we have to make in our minds a rather simple connection between a message that comes in and the action which is to follow from it. The action belongs to the message, and there is a direct connection between them.

There is a story which is mentioned by Dr. Darwin, about a little monkey in the Zoological Gardens, which shows you another kind of connection between sensation and action. There was a large baboon in the same cage, which was constantly frightening this monkey and injuring him whenever he could get at him. But once, when the keeper was sweeping out the cage and kneeling on the floor, the baboon attacked him, and bit him severely in the back of the neck. The little monkey immediately got hold of the baboon's leg, and bit it and tried by every means in his power to get him off the keeper. He was exceedingly attached to the keeper, and he wanted to get the baboon off. This you see was not a direct correspondence between any particular sensation and the particular action. You might very well say that when the monkey saw the grinning teeth and heard certain growls, that naturally suggested the

action of running away—and that, no doubt, is the beginning of the instinct by which animals save themselves from their enemies; but that would not in the least degree make him go and attack the baboon himself, when the baboon was not hurting him and was not dangerous to him, but was dangerous to the keeper.

In putting the thing in that way I could not help indicating what was the precise connection that the little monkey had made in his own mind. He had got that which we call a *proposition*; that is to say, the baboon is dangerous—not dangerous to me only, but dangerous generally—and that, you see, does not merely connect one particular sensation with a particular action that is to follow from it, but it is combined with an almost infinite variety of sensations which will indicate what is the particular action that is to flow from each of them. It would have been impossible to pack into the human brain, complicated machine as it is, all the connections that we should want between our sensations and our actions without some such artifice as this. The idea of the baboon is a group of sensations which the monkey had got, and each one of them called up all the others. When he saw his teeth he thought of his growl and his bite, and so the whole image which

he had got of the baboon was all in one piece, so that when he got a part of it it would naturally call up all the rest. But then, besides that he had tacked on to this a certain feeling which we express by the word 'dangerous'—the feeling of fear, not merely for one's self, but for other people, which, again, is an exceedingly complicated feeling, and it must have been derived from an enormous number of experiences of danger and evil, not only to him, not only that he had got, but that his ancestors had got before him. But when he had put these two into the proposition that the baboon was dangerous, it was applicable not only to the case in which the baboon was running after him, but also to the case in which he was attacking the keeper; and then we see what the action of the proposition is.

What we call a proposition, or a statement of fact, is a thing that we remember as a sentence with the verb 'is' in it. It is a sort of link which combines together not only one sensation with one action, but an infinite variety of sensations, each with its appropriate action. We do not know what the physical counterpart of that is. Nobody knows where propositions are packed in the brain, but there is every reason to suppose that it is somewhere or other in the cerebral hemi-

spheres, in the great sheet of grey matter which lies just inside of our skulls, and that the formation of anything as a proposition in our minds corresponds to the formation of certain connections between different parts of this sheet of grey matter. Mr. Bain, in his excellent book on 'Mind and Body,' has made some calculations about the room that there is in this sheet of grey matter to put in the enormous number of things that we remember; and he begins with, as I think, the very astonishing thing that there are from fifty to five hundred connections in the physical brain for every fact that we remember; that is to say, that the complexity of the physical machine, which we know, so far as it can be counted with the microscope, is very much greater than that of the mind, so far as it can be counted in a rough sort of way, by counting how many facts a particular man knows.

I want you particularly to take account of the office which the proposition or statement holds; that it does not bind together a particular sensation with a particular action, but that it is a more complicated thing, and yet that it is an enormous saving of space; that instead of having to establish a connection between each of those sensations and its particular action, we have only to establish a connection between the sensation and the proposi-

tion about it, and it will at once suggest the action which follows. That is to say, the little monkey had to combine the sensation of seeing the baboon go at the keeper with the proposition which he had already laid up in his mind that the baboon was dangerous, and thereby to know that the keeper was in danger; and then another proposition prompted the action, which was to take him out of danger—that of biting the leg of the baboon and trying to get him off.

We could then arrive so far as this, at the formation of propositions, and the guidance of our actions by those stored-up propositions, that is, by the states of our brain made out of memories of past sensations. Out of that alone, in all probability, we could have got at actions very like reason that are performed by certain solitary animals, but by far the most intelligent actions are performed by those animals which are gregarious and which go about in troops.

As you know, we think not in pictures, but in words, for the most part, and it is those words which have enabled us to make a great many steps further than the mere simple step of a proposition—the combining together of a great number of sensations with a great number of actions. As soon as men had to live together and found that

they could, by making signs, direct each other's actions, immediately there was an immense step made forward in this arrangement of propositions within our brain. We formed then, not only propositions such as 'that the baboon is dangerous,' but also *general conceptions*, as they are called. As soon as we have given a thing a name, that name does not belong to the individual thing, nor to the individual group of sensations which we get from it, but it belongs to every other thing which is like it. And this was inevitable, because if I call a thing by a name I mean that name to be attached, not to my perception of the thing alone, but to your perception also, and that is necessarily something different. A name, therefore, cannot possibly be attached to any particular sensation which I get from the thing, but it must be attached to a grouping together of all possible sensations which I could get from it, and the actions which I could perform towards it; and besides that, the possible sensations which you could get from it, and the actions which you could perform towards it. So then, you see, there is the name and the general conception which goes with it. This involves a very much closer packing even than a proposition. The whole process of the evolution of reason is an attempt to pack into an exceedingly

small box, the human brain, a picture of the enormous universe that is outside of it. Every step which was made in packing things closer together was a step in making a correspondence between our actions and the knowledge which we get from outside.

The general conception then which is involved in the use of language, in talking about things and using signs, is a still greater amount of packing. You will see this if you will try and conceive of a man who had a separate word for all the horses in London. Such a man would require a great deal more than anybody does at present. Instead of doing that, we have a general word 'horse,' and then we have other words which we can put along with it. If all that we want to know about the animal is that he is a horse, if all the connections between the sensations from him as a horse and our actions are given, as soon as you have got this word 'horse' you have got a general conception belonging to him, and that is all that we say of him. But if we want to know besides that he is a grey horse, we add that word which we know. But the advantage of having a sign is that it groups together an enormous number of propositions. Every general sign, every general word under which a great number of objects is included, groups

together all the propositions that are true of all those objects. For example, the word 'horse' tells us, not simply of an animal having a certain appearance, which can run, and trot, and so on; that proposition is included in the word, and it wraps up together all such propositions as these. All the characteristics of the horse which are suggested to me by his appearance are wrapped up in the general conception, so that instead of remembering one of these propositions separately, that the animal was of a particular appearance, and could run fast, and will let me ride upon him if he has been properly trained, and so on, all this last string of propositions about the horse is bound up in the word. That is a still closer packing than we get in the proposition itself.

Now the wonderful thing to remember here is, that the world in which we all of us live is not made up out of those individual sensations of objects for the most part, but it is made up out of the general conceptions. If you try to think of what has passed through your mind during any day, you will find that a very small part of it is made up of those special sensations of sight and sound which you get from things, but that it is made up of suggestions and thoughts which arise out of them, and which were carried on by means

of language, which were carried on therefore by the help of those general conceptions, and not by the help of the particular perceptions of individuals included under them. The world in which we live is a world of thought and not of sensation. How was this world of thought made? It was made, as we said, by man being a gregarious animal, and by a correspondence being established not only between the actions and the sensations of each particular man, but by a similar correspondence being established between the actions and sensations of all those different men. As soon as language arises, it is quite enough for me to see a horse and to tell you so, and that is the same to you for certain purposes as if you saw a horse yourself. A correspondence is therefore set up between the sensations of one man and the actions of another, and that is what lies at the basis of society.

Then the formation of these general conceptions, —what is it? what has guided it? Why, clearly, the use of them to society, and not the use of them to individuals. We pack these propositions together into words, into general conceptions which are useful to talk about. So that the world in which we live is one which has come to exist in our minds, not from anything which could have happened to us as individuals if we had not lived

together, but from the fact of our living together; and in the conceptions which we get of anything that we look at together. There is not merely a grouping together of all our previous experience of that thing, but there is a binding up of all the previous experiences of the race. If I look at the sky I may think of it merely as a great vault of clouds with beautiful colours moving about and exciting my feelings in a certain way. I do not remember at the time what it is that has formed all these ideas and that has bound them together; but it is just the previous feelings, the feelings that have been previously in the mind of my ancestors, and especially of those who have spoken the language that I do. Those men who have looked at the sky have, one after another, felt all these different feelings about it, and some of them have expressed them as poets, and have bound them up in language that we speak, and therefore have made the sky to be to us what it is.

If, on the other hand, I go out on a cloudless night and look at all the stars, and if I remember that they are all at different distances from one another, that they are all arranged in constellations, and that they move round the poles in circles with a uniform movement—these conceptions which have come into my mind are not produced by my

own sensations. They are not merely groupings together of things which I have seen, and of actions which have flowed from them, but they are produced by the grouping of sensations and of actions in the minds of observers and astronomers who have gone before, and who have made those ideas lie imbedded in our language, so that they instantly come up into our minds. Again, if I not only see a number of stars at certain definite distances, and know that they can be seen to revolve about the pole; but if also I observe some of them to be planets, I remember that they are revolving about the sun in definite ways, and that they all form a great system which is in obedience to definite laws; I am using conceptions which have been put into our language, and have been made possible for my mind, not by my own thoughts, nor by any sensations that I have had, nor by any experience that has come to me, but by the previous thoughts of theorists and great natural philosophers—of Newton and his successors.

So then you see it is the thought of past humanity imbedded in our language which makes Nature to be what she is for us; and the world in which we live is a world of general conceptions, and these are determined by language and expressed by signs. If the way in which these

general conceptions are bound together has been determined by the previous thought of society, it follows that our ancestors have made the world to be what it is for us—that is to say, what it is to all those who have studied nature, whether as scientific men or as artists. They have felt that out of the things that they studied something like a similar intelligence was looking at them. If a scientific man looked at the stars, and considered their motions, it seemed to him as if he was in the presence of an intelligence and was talking to somebody; and it was the thought of Plato, and of Aristotle, and of Hipparchus, and of Ptolemy, and subsequent astronomers, which was bound up in his notion of the heavens, that all those great men were actually talking to him whenever he looked at the stars.

In the same way the poet, when he looks round upon a beautiful scene in nature, feels as if he were looking upon the face of a friend. All the sensations of beauty that have been in the minds of previous poets are embedded in language, in the general conceptions by means of which he thinks of this scene, and it is they who are looking out with their dead eyes upon the scene which he sees around him. What is it then that the thinker does? If we call a man a thinker we mean that

he takes and puts something into the stock of conceptions which humanity has got which was not there before, and he does this in either of two ways. He either arranges the old ones, showing which of them will go together and which will not, and arranges them all into a system, culling out from them inconsistencies; or he observes facts, and makes new conceptions, which are then embodied in the ideal of nature which is formed by people who come after him. These two things, the arranging of the old signs and the making of new ones, are the great work of the thinker, either of the poet or the scientific man or the artist.

We have so far then successfully built up, out of one elementary process, the correspondence of action to sensation; we have got as far as what takes place in the mind of the thinker who combines together our old signs, or re-arranges them, and produces new ones out of them. We first of all combined a number of very simple messages coming along the nerves by means of a lump of grey matter; we then combined a number of outgoing messages by means of another lump of grey matter, and produced a complicated action; then we combined these together by means of propositions, so that any number of complicated sensations coming in could find their appropriate

propositions, and by being coupled with them could bring about the appropriate action ; and, lastly, we have combined together a great number of propositions into a general conception which is expressed in language, and which requires language in order to express it, and that is what makes for us a picture of the universe, which is the one we have in our minds from day to day, although it is not the one which we immediately see when we get particular perceptions.

But there is one class of these connections between sensation and action which are of extreme importance. You can easily see that, as soon as the whole process has become so complicated as we have now described it to be, it is quite possible either for two sensations coming at once to impel to two different courses of action that have to be chosen between, or else for one sensation coming in to call up the memory of past sensations, and for these two then existing together to call for two different courses of action. Which of these is actually taken by the organism will, of course, depend upon the strength of them.

Now let us see what it is that determines the strength of them. When a sensation comes in, and there is time to deliberate about it, and to act voluntarily, messages go out from that part of the

brain which receives these messages, and go out to all parts of the cerebral hemisphere, and there they are compared together. So, then, if two sensations come in together, these messages will go out from each of them to all parts of the cerebral hemisphere, and they will also be compared together. But that one which has the strongest connection with the memories of past sensations leading to a certain action—if that is all that takes place, if only the cerebral hemispheres themselves are consulted—will have the strongest effect upon the muscles, because it will excite the greatest number of outgoing messages.

But another thing may happen. We said that in order that a sensation should issue in action, it was necessary for the mind, or, looking at the other side, it was necessary for the brain, to be in a certain prepared state, and this prepared state was what we called an emotion, or an appetite. It may be that one sensation will arouse an emotion when another will not. All that depends upon the nature of the message which is sent down from the cerebral hemisphere in consequence of the second sensation which does not arouse the emotion, whether that is strong enough to overcome the strength of the message which has come from the other in consequence of its arousing the emotion.

Dr. Darwin, in a passage which I will take the liberty of quoting, has pointed out that this takes place with regard to certain emotions or instincts which arise out of the fact of men living together. He says: 'The social animals which stand at the bottom of the scale are guided almost exclusively, and those which stand higher in the scale are largely guided, in the aid which they give to members of the same community, by special instincts; but they are likewise in part impelled by mutual love and sympathy, assisted apparently by some amount of reason. Although man, as just remarked, has no special instincts to tell him how to aid his fellow-men, he still has the impulse, and, with his improved intellectual faculties, would naturally be much guided in this respect by reason and experience. Instinctive sympathy would also cause him to value highly the approbation of his fellow-men; for, as Mr. Bain has clearly shown, the love of praise, and the strong feeling of glory, and the still stronger horror of scorn and infamy, "are due to the workings of sympathy." Consequently man would be greatly influenced by the wishes, approbation, and blame of his fellow-men as expressed by their gestures and language. Thus the social instincts which must have been acquired by man in a very rude state, and probably even by his early

ape-like progenitors, still give the impulse to many of his best actions; but his actions are largely determined by the expressed wishes and judgment of his fellow-men, and unfortunately still oftener by his own strong, selfish desires. But as the feelings of love and sympathy, and the power of self-command become strengthened by habit, and as the power of reasoning becomes clearer, so that man can appreciate the justice of the judgments of his fellow-men, he will feel himself impelled, independently of any pleasure or pain felt at the moment, to certain lines of conduct. He may then say, I am the supreme judge of my own conduct, and, in the words of Kant, I will not in my own person violate the dignity of humanity.' Then he says: 'We have, however, not as yet considered the main point, on which the whole question of the moral sense hinges. Why should a man feel that he ought to obey one instinctive desire rather than another? Why does he bitterly regret if he has yielded to the strong sense of self-preservation and has not risked his life to save that of a fellow-creature? or why does he regret having stolen food from severe hunger?

'It is evident, in the first place, that with mankind the instinctive impulses have different degrees of strength; a young and timid mother, urged by

the maternal instinct, will, without a moment's hesitation, run the greatest danger for her infant. Many a man, or even boy, who never before risked his life for another, but in whom courage and sympathy were well developed, has, disregarding the instinct of self-preservation, instantaneously plunged into a torrent to save a drowning fellow-creature. In this case man is impelled by the same instinctive motive which caused the heroic little American monkey, formerly described, to attack the great and dreaded baboon to save his keeper. Such actions as the above appear to be the simple result of the greater strength of the social or maternal instincts rather than of any other instinct or motive; for they are formed too instantaneously for reflection, or for the sensation of pleasure or pain; though, if prevented, distress would be caused.

'I am aware that some persons maintain that actions performed impulsively, as in the above cases, do not come under the dominion of the moral sense, and cannot be called moral. They confine this term to actions done deliberately, after a victory over opposing desires, or to actions prompted by some lofty motive. But it appears scarcely possible to draw any clear line of distinction of this kind; though the distinction may be real. As far as exalted motives are concerned,

many instances have been recorded of barbarians destitute of any feeling of general benevolence towards mankind, and not guided by any religious motive, who have deliberately, as prisoners, sacrificed their lives rather than betray their comrades; and surely their conduct ought to be considered as moral. As far as deliberation and the victory over opposing motives are concerned, animals may be seen doubling between opposed instincts, as in rescuing their offspring or comrades from danger; yet their actions, though done for the good of others, are not called moral.'

'But to return to our more immediate subject; although some instincts are more powerful than others, thus leading to corresponding actions, yet it cannot be maintained that the social instincts are ordinarily stronger in man, or have become stronger through long-continued habit, than the instincts, for instance, of self-preservation, hunger, lust, vengeance, &c. Why then does man regret, even though he may endeavour to banish any such regret, that he has followed the one natural impulse rather than the other; and why does he further feel that he ought to regret his conduct? Man in this respect differs profoundly from the lower animals. Nevertheless, we can, I think, see with some degree of clearness the reason of this difference.

'Man, from the activity of his native faculties, cannot avoid reflection; past impressions and images are incessantly passing through his mind with distinctness. Now, with those animals that live permanently in a body the social instincts are ever present and persistent. Such animals are always ready to utter the danger signal, to defend the community, and to give aid to their fellows in accordance with their habits; they feel at all times, without the stimulus of any special passion or desire, some degree of love and sympathy for them; they are unhappy if long separated from them, and always happy to be in their company. So it is with ourselves. A man who possessed no trace of such feelings would be an unnatural monster. On the other hand, the desire or any passion, such as vengeance, is in its nature temporary, and can for a time be fully satisfied. Nor is it easy, perhaps hardly possible, to call up with complete vividness the feeling, for instance, of hunger; nor indeed, as has often been remarked, of any suffering. The instinct of self-preservation is not felt except in presence of danger; and many a coward has thought himself brave until he has met his enemy face to face. The wish for another man's property is perhaps as persistent a desire as any that can be named; but even in this case the satisfaction of

actual possession is generally a weaker feeling than the desire. Many a thief, if not an habitual one, after success has wondered why he stole some article.

'Thus, as man cannot help old impressions continually repassing through his mind, he will be compelled to compare the weaker impressions of, for instance, past hunger or of vengeance satisfied, or danger avoided at the cost of other men, with the instinct of sympathy and good-will to his fellows which is still present, and ever in some degree active in his mind. He will then feel in his imagination that a stronger instinct has yielded to one which now seems comparatively weak; and then that sense of dissatisfaction will inevitably be felt with which man is endowed, like every other animal, in order that his instincts may be obeyed. The case before given of the swallow affords an illustration, though of a reversed nature, of a temporary though for the time strongly persistent instinct conquering another instinct which is usually dominant over all others. At the proper season, these birds seem all day long to be impressed with the desire to migrate; their habits change; they become restless, are noisy, and congregate in flocks. Whilst the mother-bird is feeding or broading over her nestlings, the maternal instinct is probably

stronger than the migratory; but the instinct which is more persistent gains the victory, and at last, at a moment when her young ones are not in sight, she takes flight and deserts them. When arrived at the end of her long journey, and the migratory instinct ceases to act, what an agony of remorse each bird would feel if, from being endowed with great mental activity, she could not prevent the image continually passing before her mind of her young ones perishing in the bleak north from cold and hunger.

'At the moment of action man will no doubt be apt to follow the stronger impulse; and though this may occasionally prompt him to the noblest deeds, it will far more commonly lead him to gratify his own desires at the expense of other men. But after their gratification, when past and weaker impressions are contrasted with the ever-enduring social instincts, retribution will surely come. Man will then feel dissatisfied with himself, and will resolve with more or less force to act differently for the future. This is conscience; for conscience looks backwards and judges past actions, inducing that kind of dissatisfaction which, if weak, we call regret, and if severe, remorse.'

These passages from the 'Descent of Man' show how it is that from the last point of communication

and correspondence between the sensations and the actions of many people instead of one, we arrive at that feeling which is perhaps the most complicated of all, and the one which is the first attacked by mental disease in man, namely, the feeling of conscience. We see that this is an emotion which is aroused whenever there is a conflict coming on between an immediately selfish instinct and our present social instinct.

Now then, having seen in what that feeling consists, let us just consider why it is that we call one man 'good;' and another man 'bad.' If a man has done a certain action, and we consider it to be a bad action, we subsequently punish him for it; and we either punish him outwardly by shutting him up in prison, or by thrashing him, or else we make him feel social disapprobation, which is a thing which no doubt makes him exceedingly uncomfortable, and which rouses the voice of his conscience, which acting persistently upon a body of men will ultimately modify their actions so as to make them do that which is useful to society.

In doing so, in expressing our disapprobation of any man's action with the hope of making him better in future, we are assuming, not merely that he has done this particular thing, but that he is such a man as would do it again, and also that

by rousing his conscience, by rousing the social instinct in him, we shall be able so to alter his character that he will in future not be such a man as to do the same thing again. It seems to me that unless that assumption is made, unless some inference can be drawn about his character from the actions which a man has committed, and unless some influence is brought to bear upon that character, so as to have an effect upon his future actions, it would be a most senseless thing ever to express disapprobation, or in any way to punish him for a fault which he has committed. This act of punishment and disapprobation in the faintest degree implies that you can do some good with it, and therefore some good is to be done with it. It implies, therefore, that you are able to infer from a man's actions something about him, something about his character which he carries about with him; that is to say, you are able to infer from what a man does what is the nature of that extremely complicated mechanism in his body which determines the relation of sensation to action, and what is the nature of that other extremely complicated fact, which is his mind; that is to say, what is the aggregate of laws which rule over the succession of his feelings.

From the conclusions to which we have been

led about the nature of the connection between sensation and action, namely, that the particular action which, in a given man, will follow from a particular sensation is determined by the character of the man, that is to say, by the nature of the connections which have been set up in him between sensations and actions—it follows that it is a perfectly right thing to say to a man, 'Such an action is right, or such an action is wrong,'—that is to say, this action will be approved of by right-thinking people, and the other action will be disapproved of; because by saying this to a man, and by making him feel that he will meet with disapprobation if he does the wrong action, it is possible to produce an effect upon his character which will subsequently affect his actions. But it seems to me, and here, of course, I am expressing only an individual opinion, that if that is not the case, if there is really no connection between what a man is and what he does under given circumstances, if you have no right either to infer his character from what he has done, or to expect by changing his character to alter what he will do—it seems to me a perfectly senseless and useless thing to talk about one action being right and another action being wrong.

I said, if you remember, in my first lecture, that the subject on which I had to address you was a

sort of Clapham Junction of all the sciences—that they all lead up to it and that they all draw something away from it. You see that we have gone over facts, some in the domain of physics, when we considered what was the physical nature of the nerves and the transmission of messages along them, and especially when we considered the nature of the messages which light takes into the eye. And we have gone over facts in the domain of physiology, in the actions of living creatures, and when we considered the structure of the brain and the way in which it moved. And we have now come to another order of consideration altogether, that of those sciences which are called mental or moral, and which deal with the laws of the human mind, and especially with the laws of right and wrong.

I can only hope in conclusion that I shall lead you to study any one of the several points which will be found in time to diverge from those points which we have been considering.

OF BOUNDARIES IN GENERAL.

BEFORE I begin to talk to you about the sizes and shapes of things, I am going to make a request that may seem somewhat strange. I am going to ask you to forget that you have ever lived until this moment. It is not that I am going to tell you anything new, that you did not know before; for I am merely going to remind you of a lot of things that you have known familiarly for years. Only I want you to observe them all quite freshly over again, as if you had not seen them before. I want you not to believe a word I say, unless you can see quite plainly at the moment that it is true; and I shall try only to say such things as you can quite easily verify at once while you sit there. That is what I mean by asking you to forget that you have ever lived until this moment: for geometry, you know, is the gate of science, and the gate is so low and small that one can only enter it as a little child.

Things take up *room.* Let us examine this

fact rather closely. Here is a piece of wood which takes up room; that is to say, there is some room which is taken up by the wood, and some room which is not. Any *thing*, then, implies two rooms or spaces; one in which it is, and one in which it is not; one which it takes up or fills, and one which it does not fill; an *inside* space and an *outside* space. But it is not every two spaces that are so situated with regard to each other as these spaces are. Here, for instance, is a glass of water. The water also takes up room, and makes a difference between the space where there is water and the space where there is not water. We are now considering those spaces; that in which there is this piece of wood, that in which there is this water, and that in which there is neither. Now if you try to go from any part of the wood-space to any part of the water-space, you will find that it is impossible to do so without passing through space which is neither wood nor water. But you can go from any part of the space where this piece of wood is to any part of the space where this piece of wood is not without passing through anything but these two spaces; and that in as many ways as you like. If you are inside the wood, you can get to the outside air without going through anything but wood and air. This property of the

two rooms or regions, the inside and the outside, which are distinguished by everything, is denoted by the word *adjacent*, which means *lying close up to.* To say that two regions or spaces are adjacent is the same thing as to say that you can get from one to the other without going through anything but those two regions; and that in as many ways as you like.

The observation, then, that we have made so far is this. Every thing divides all space into two adjacent regions, the *inside* and the *outside.* Here I have scarcely spoken quite correctly. The thing takes up one of the two regions, and does not take up the other; so it constitutes the difference between them: but that which *divides* the one region from the other is not the thing itself, but the *surface* of the thing. In the case of this water, for example, there is a certain region taken up by the water in the glass, and a certain region taken up by the air above it; and the surface of the water is what divides one of those regions from the other; it is the *boundary* between them, which marks them off. Now there are four things to be noticed about this surface. They are things quite obvious and easy to be noticed, things that you have all noticed before; but it is important that we should state them explicitly, and agree that we have observed them. *First*, it is the *sur-*

face of *both* of those regions into which space is divided by it. The upper surface of the water is also the lower surface of the air.

If you like to see this in a very striking way, all you have to do is to lift up the glass of water until you can see the image of something reflected in that air-surface. It is a surface of wonderful brilliancy, reflecting in certain cases all the light which falls upon it. Now I can see the image of a part of the tea-spoon in the figure formed by the surface of the air. This very simple experiment will enable you more easily to realise this fact, that what you call the surface of the water, when you view it from the air-side, is precisely the same surface as that which you call the surface of the air when you view it from the water-side. And the same remark is true of all other cases. Looking at this piece of wood from the outside, we should talk about the surface of the wood; that is to say, the surface of the inside space. But if we imagine our point of view transferred to the inside, we should talk about that very same surface as the surface of the air, that is to say, the surface of the outside space. So that until our point of view has been changed, we are apt to have a partial and one-sided notion of a surface.

The *second* remark that we have to make about

FIG. 8.

a surface is that it takes up absolutely *no* room at all. This is the same thing as saying (what we said before) that the two regions into which space is divided by the surface are *adjacent*, that where one ends the other begins, namely, at the surface of both of them. Between water and air, for instance, there is absolutely no room at all ; there is only the surface common to these two things. So that a surface has not even any right to be called a thing, in the sense in which things take up room. Possibly some one thinks that the surface of this piece of wood is a thin film of wood which is just outside all over it. Well, then, that is just what it is *not*. Suppose that I dipped the wood into water, and made it wet, leaving a very thin film of water all over. Would that film be a surface ? No ; for it would take up room. The film would have two surfaces—one outside, between water and air, and one inside, between water and wood ; and there would be room between those two surfaces, namely, the room taken up by the water of which the film is composed ; which, being a thing, must take up room, however little there is of it. And half way between those two surfaces there might be another, dividing water that was outside it from water that was inside it ; and, again, between that and each of the others there might be

two more, and so on, as many times as you like; and still between two of these, however close together, there would be water, a thing taking up room, with one surface on the outside of it and one surface on the inside. Is this sheet of paper a surface? No; it has a surface above and a surface below. And if you were to split—not the sheet of paper, for that would be impossible—but the sheet of space in which the paper is, into a million sheets, and to-morrow one of those again into a million sheets, and the next day one of those into a million sheets, and if you kept up that process for a million years, the inconceivably thin sheet that you would have at the end would still be room, with a surface above and a surface below; it would be no nearer to being itself a surface than when you began. You see it is quite easy to say that a surface takes up no room; but it is not so easy to realise the enormous gulf that is fixed between very little and none at all. And when Euclid tells you that a surface has length and breadth, but *no thickness*, he means exactly what we have just been observing.

The two other points that we have to notice are about the *motion* of a thing. If I move this piece of wood about, I also move the surface of the wood. We must therefore regard a surface as

capable of being moved about. Now there is a property of every motion that takes place, which is also a property of this motion of a surface; a property which is, no doubt, implied in our ordinary use of the word *move*, but which is not always sufficiently prominent in it. This motion is *continuous*. Now the idea expressed by that word *continuous* is one of extreme importance; it is the foundation of all exact science of things; and yet it is so very simple and elementary, that it must have been almost the first clear idea that we got into our heads. It is only this: I cannot move this thing from one position to another, without making it go through an infinite number of intermediate positions. *Infinite*; it is a dreadful word, I know, until you find out that you are familiar with the thing which it expresses. In this place it means that between any two positions there is some intermediate position; between that and either of the others, again, there is some other intermediate; and so on *without any end*. Infinite means without any end. If you went on with that work of counting for ever, you would never get any further than the beginning of it. At last you would only have two positions very close together, but not the same; and the whole process might be gone over again, beginning with those as many times as you like.

But, you will say, what is the use of telling me that motion is continuous, when I cannot conceive of it as being anything else? Then I will try to tell you what discontinuous motion would be like. If this piece of wood were to be annihilated as soon as it got here, and then to come into being again over there, so as to have got from one position to the other without passing through any intermediate positions, its motion would be discontinuous. It would go by a jump from one place to another; and continuous means *holding together* all through, without any jumps. But this would not be *moving*, you will say; and besides, the state of things is impossible. Very well; I said (if you recollect) that the idea of continuity was implied in the word move, and that it was so exceedingly simple and elementary that it must have been almost the first clear idea that got into our heads. It is no wonder, then, that it should be firmly lodged there now. At another time we may be able to see some of the consequences of this idea. At present we have only to remember our third observation about surfaces; that any surface may be moved continuously from one position to another.

Now a surface, you will remember, is that which separates two different regions of space; the difference between them being that something is in

one and is not in the other. But two regions of space may differ in this way: that, five minutes ago, a thing *was* in one of them and was not in the other. These two regions are still adjacent, still separated by a surface. So that although a thing is moved away and its surface is moved away with it, yet it is also true that the surface remains in the same place. It is no longer the surface of the thing, but it is the surface of those two regions which *were* marked out by the thing. The two regions, of course, are always there, and from having been different once they are distinct for ever. Thus when anything is moved you see that there must be an infinite number of surfaces, each of which has at some instant or other been the surface of the thing. Now here there are two cases to be distinguished. Consider the surface of this water; when I agitate it the water moves about, and the surface continually changes. All this time the water has been changing its shape, and at any one instant it would not fit the surface which it had at any other instant. But if I move this piece of wood, which does not change either in size or shape, the surfaces which it has at different times are such that any one of them would fit the wood at any time; they are all exactly of the same shape, and all exactly of the same size. This being so, the regions of

space which are filled by the wood at two different times are called *congruent* regions. Two regions of space are congruent when a thing which exactly fills one of them can be made exactly to fill the other by moving it, without changing its size or shape. Or we may express the same thing by saying that the surface of the two regions can be put together so as to fit each other all over.

Let us now put together the observations that we have made so far. Only instead of the word *thing*, which I have used hitherto, I want to use the word *body*, which is rather more accurate. A body is anything that takes up room. This piece of wood is a body; the water in the glass is a body; the air all about is a body. We have observed, then, that every body discriminates two adjacent regions of space; that the surface of the body divides these two regions from one another; it is surface to both of them equally; it takes up no room; it can be moved continuously with the body, and yet it remains when the body is taken away. We have also given a name to those regions which are of the same shape and size: we have called them congruent regions.

Now if you will look at the surface of this sheet of paper you will observe that a part of it is coloured red. That red patch takes up room on

the surface; but this is surface-room that is taken up, a different kind of room from that which is taken up by a solid body. The red colour distinguishes between two regions of the surface, precisely as a body distinguishes between two regions of solid space. And the two surface-regions are adjacent; that is to say, you can get from red to white on the surface without going over any part of the surface except red and white; exactly where the red ends the white begins. That which divides one of these surface-regions from the other is the boundary-*line* of both of them. This line is neither white nor red; it takes up no room whatever on the surface. If with a very fine pen I try to draw a line on the surface, what shall I in fact have done? I shall have made a portion of the surface black, and the boundary of the black portion is a line. It is certainly a long narrow portion that I have made black, so that we may say it has a line on one side, and a line on the other side. Between those two lines there is an infinite number of other lines. No matter how microscopically fine was the mark that you made, it would always be a portion of the surface that you had made black, a region taking up surface room. There would always be a line on one side and a line on the other side, separating black from white, and between these two there would always be an infinite number of lines.

Moreover, if I move this sheet of paper about, I shall move about all the lines that are on its surface. And yet the lines will remain where they were. For there is a distinction between the space where at any instant paper was and the space where paper was not ; and of the surface that parts those two spaces there is a distinction between that which was surface of red paper and that which was surface of white paper. The boundary between these two surface-regions is a line, still existing, because the distinction between those two surface regions still exists. A line may even move upon a surface while the surface remains still. If, for instance, we cast a shadow on the paper, then the boundary of light and shade is a line ; and when we make the shadow move about the line moves about too, though it still remains to mark the distinction between what was shadow and what was not shadow.

Thus, you see, all the remarks that we made about regions of solid room and their boundaries have their counterparts when we come to speak about regions of surface-room and their boundaries. But there is one more remark to be made here, which is not similar to any that we have made before. And that is, that a line may be regarded from two entirely distinct points of view.

One of these we have already considered. We have already looked upon a line as the boundary between two adjacent regions of surface, and we have noticed the analogy beween this idea of a line and the idea which we have previously formed of a surface as the boundary between two adjacent regions of solid space. But now, suppose that I dip a part of this piece of paper into water; and please to imagine that the surface of the water goes on through the paper to the other side, and is not stopped by it. Then there is a line upon the surface of the paper, viz. the line which divides paper-surface which is in water from paper-surface which is out of water; and there is also a line upon the surface of the water, viz. the line which divides the water-surface on one side of the surface of paper from the water-surface on the other side. And these two lines are exactly the same line; a single line lying both on the paper-surface and also on the water-surface. Moreover, if you were asked, 'Where do those surfaces meet?' you would answer, 'They meet in that line which is common to them both.' It is just at that line that each surface *intersects* the other, or *cuts between* two portions of it, which are thereby separated. So that the line is to be considered as existing in space, quite independently of the particular surface which it divides

into two portions. It might be possible to agitate the water or move about the piece of paper so as to leave the line quite still, and in that case there would be an infinite number of surfaces all passing through the line. Now when I say that the line exists independently of the particular surface which it divides, I do not mean that you can get at the idea of a line without thinking of a surface which it divides, but that there is no reason why out of that infinite number of surfaces you should choose any one in particular. You must have *a* surface, but you are not bound to any *one.*

A line, then, is not only the boundary between two adjacent regions of a surface, but also it is the *intersection* of two surfaces.

Let us return to the contemplation of the red patch on the surface of this paper. Especially consider the line which bounds it. I will throw a shadow on part of the line. Now the shadow takes up line-room; there is a part of the line which is in shadow, and a part of the line which is not in shadow. That which divides one of these parts from the other is the *point* which is the boundary of both; which marks where one of them ends and the other begins. The point takes up no room of any kind whatever, not even line-room, the last kind that we have considered. Here,

then, we have come to something quite different from the other two boundaries that we talked about. A body takes up more or less space; it is quite intelligible to ask how much space it fills. So a patch may take up more or less surface, and you may say, 'How much line does the shadow cover?' But if you said, 'How much point?' you would be talking nonsense; that is to say, you would be putting words together when the ideas that correspond to them will not go together. The idea of *how much* is utterly foreign to the idea of *point*. Point cannot be measured; there are no parts of it to be distinguished from one another. Here we are at the first word of Euclid: a point is that which has no parts, or which has no magnitude. Only we are much richer than any one who begins at that first word, for we are making a statement which we see to be true about something which we know independently of that statement, and which, moreover, we can look at in four different lights. A point, namely, is not only a boundary, and so may have made about it the remarks that we have made about other boundaries, but it is an intersection, and that in three several ways. First, it is the intersection of two lines on a surface; for instance, of this boundary of red crossed by the boundary of shadow. There is a point on the first line, dividing

light from shade, and a point on the second line dividing red from white; and these two are the same point, common to the two lines. At this point the two lines meet, and each intersects the other, or cuts between two parts of it which are thereby separated. Next, it is the intersection of a line and a surface, dividing that part of the line which is on one side of the surface from that part of the line which is on the other side; as when I dip a piece of paper which is half red into water, there is a point dividing that part of the red boundary which is in water from that part which is out of it. And lastly, a point is the intersection of three surfaces, a remark which you will find easy to illustrate, *e.g.* by the corner of a room, which is the intersection of the surfaces of the two walls and of the floor.

We have now considered in succession four different ideas: solid space or volume, surface, line, point, and we have regarded each of them as the boundary between two adjacent regions of the preceding. It remains for us to go straight back again over the same route, to consider in succession point, line, surface, volume, regarding each as the *path* of the preceding. For when a point moves, it moves along some line; and you may say that it traces out or describes the line. To look at something

definite, let us take the point where this boundary of red on paper is cut by the surface of water. I move all about together. Now you know that between any two positions of the point there is an infinite number of intermediate positions. Where are they all? Why, clearly, in the line along which the point moved. That line is the place where all such points are to be found. But because this statement, so made, is quite simple and sensible and easy to be understood, we must needs translate it into Latin, and say, 'The line is the *locus* of the successive positions of a moving point.' Locus means merely place, both naturally and technically. There is no meaning whatever in the statement 'That line is the locus of the successive positions of a moving point' which is not fully and entirely conveyed by this other statement of the same thing: The line is the place where all those successive positions are.

I have laid some stress on this, because it seems to be a fair opportunity for warning you of a very serious danger: the danger of thinking that there is any mystery in a technical term. So long as you use it merely to save time and trouble, as an abbreviation, namely, for other simple words or phrases which everybody can understand, a technical word will be useful and harmless. But directly

you begin to think that there is some hidden and mysterious meaning in it, which cannot be expressed in simple ordinary words that everybody could understand, there is no end to the nonsense that it will help you to think and talk. And when I have been using technical words, and am not quite sure whether I have been talking nonsense or no, I have one very safe way of finding out. I translate the whole thing into English, that is to say, into short easy words of Saxon origin. For there is an amazing amount of mystery in Latin and Greek terminations ; and so long as any of these are left, I am never quite certain that I know what I mean.

Then you must not imagine that the Latin word *locus*, as used in geometry, means anything more or less than the English word place. When a point moves along a line, that line is the *locus* of the successive positions of the moving point, or the *place* where they all are.

In an exactly similar way, if a line moves about, it traces out a surface, which is called its path. Between any two positions of the line, there is an infinite number of intermediate positions ; and the surface is the place where all these are, or the locus of the successive positions of the moving line. Lastly, by the motion of a surface a solid space or

volume is traced out; and this volume may be called the path of the surface or the locus of its successive positions. Thus we have three kinds of *room*, solid-room, surface-room, and line-room; and three several *boundaries* to them, surface, line, and point; four *intersections*, surface with surface, surface with line, line with line, and three surfaces together; and three *paths* whereby a boundary, moving, may trace out that of which it is a boundary; namely, a solid is the path of a surface, a surface of a line, and a line of a point.

But we have not quite done with this last idea. We have first to make ourselves secure against a possible mistake about it, and then to observe some very important consequences that flow from it.

It seems a very natural thing to say that space is made up of points. I want you to examine very carefully what this means, and how far it is true. And let us first take the simplest case, and consider whether we may safely say that a line is made up of points. If you think of a very large number—say, a million—of points all in a row, the end ones being an inch apart; then this string of points is altogether a different thing from a line an inch long. For if you single out two points which are next one another, then there is no point of the series between them; but if you take two points

on a line, however close together they may be, there is an infinite number of points between them, The two things are different *in kind*, not in degree. The failure to make a line does not mean that you have not taken a large enough number, but that *number itself* is essentially inadequate to make points into a line. However large a number you imagined, we might divide an inch into that number of parts, and each of these parts would be a little piece of line-room with a point at each end of it, and an infinite number of points between them. So that if, when you said 'A line can be made up of points,' you meant this: 'If I count a large enough number, and take that number of points, and lay them in a row, then I shall make a line,' it would not be true. It is not at all true that a line can be made up of points in that way. Nor is it any more true in that sense that a surface can be made up of lines, or a solid of surfaces. If you took millions and millions of lines and laid them side by side, you would have something which is not a surface at all, but an entirely different thing, viz. a large number of lines. Between two of those lines there would be nothing belonging to the series of lines; but between two lines on a surface, however close together they are, there is always a little strip of surface-room, in which an

infinite number of lines can be drawn on the surface. And so if you took any number of surfaces, it would be utterly impossible to make a solid with them. Two of your surfaces must either be distinct, in which case there would be solid room between them; or they must coincide, in which case they would take up no more room than one surface, that is to say, absolutely none at all. So far, then, it would appear that we must answer *no* to the question 'Is space made up of points?'

In fact, when we said that there is an infinite number of points in a piece of line-room, we might have said a great deal more. Suppose, for instance, that anyone said, 'How many miles is it possible to go up into space?' the answer would of course be, 'An infinite number of miles.' (Don't be frightened at this continual occurrence of the word infinite: it still means 'without any end,' and nothing more.) In this case, if you go a mile and count one, then another and count two, and so on, all we mean is that the process would never end. There would still be space left to go up into, however many millions of miles you had counted. But still all those miles would be counted and done with. Your task would have been distinctly begun, and there would be nothing more to say to the miles behind you. But try now to count the

points in a piece of line. You count one, two, three, four, a million points; and your task is not even begun. The line is all there, exactly as it was before; absolutely none of it is done with. The million points take up no more line-room than one point; that is to say, absolutely none at all. When then we are talking of the points in a piece of line, we must say not merely that there is a never-ending number of them (which there is), but that they are out of the reach of number altogether. All the points in a line are not, properly speaking, a number of points at all. If we are going to speak about the *number* of points in a line, we must settle beforehand that we are going to use the word in a new sense, which is not derived from counting, but from this very observation to which we have applied it.

Let us now make use of our idea of a path. When a point moves along a line, we know that between any two positions of it there is an infinite number (in this new sense) of intermediate positions. That is because the motion is continuous. Each of those positions is where the point was at some instant or other. Between the two end positions on the line, the point where the motion began and the point where it stopped, there is no point of the line which does not belong to that series. We

have thus an infinite series of successive positions of a continuously moving point, and in that series are included all the points of a certain piece of line-room. May we say then that the line is made up of that infinite series of points?

Yes; if we mean no more than that the series makes up the *points* of the line. But *no*, if we mean that the line is made up of those points in the same way that it is made up of a great many very small pieces of line. A point is not to be regarded as a *part* of a line, in any sense whatever. It is the boundary between two parts. The parts of a piece of solid room are smaller pieces of solid room, and not surfaces. The parts of a piece of surface are smaller pieces of surface, and not lines. The parts of a piece of line are smaller pieces of line, and not points. So you must be very careful to remember that a line is a different thing from the aggregate of all the points upon it; the points are on the line, but they are not the line itself. And the same distinction must be kept between a surface and all the positions of a line which traces it out; the surface is the place where all the lines are, but it is not the lines themselves. Finally, there are innumerable points and lines and surfaces in solid space; but space itself is essentially a different thing from all of them, which can be traced

out by their continuous motion, but cannot be built up by putting them together.

On the whole, then, we must answer *no* to the question that we have discussed. To say that space is made up of points would be to say that space is the same thing as all the points in it, which is certainly untrue. And we may now, I think, without fear of mistake, use the word number in that extended sense which we proposed to give to it. We said, you remember, that in speaking of the number of points in a line, we must mean a great deal more than when we speak of the number of miles that you can go before coming to the end of space. For this last number is a number of *parts.* Every mile is a part of the whole distance; an immeasurably small part, of course, but still a distance, a thing of the same kind as the whole distance. But the other number is not a number of parts; it is a number of points which trace out a line not by *repetition* of themselves, but by *continuous motion.* And the idea which you have to attach to the word number is not to be got from elsewhere, but from the contemplation of this fact itself. I can recommend it as a very fruitful subject of contemplation, which has led people to the most important discoveries.

The number of points on a piece of line is *singly*

infinite. You understand all this now, excepting the word *singly.* And that is what I am going to explain. Let us consider what is the number of points on a piece of surface. It is at least infinite, for if you draw any line on the surface, all the points on that line must be reckoned, and there is an infinite number of them. But it is more than that. For when you have traced out a line by the continuous motion of a point, you can trace out the surface by the continuous motion of that line; so that first you have an infinite number of points on the line, and then an infinite number of these infinities. Thus you see that the number of points on a piece of surface is twice as infinite as the number of points on a piece of line; or, as we are accustomed to say, the former is *doubly infinite,* and the latter *singly infinite.* Let us next consider what is the number of points in a piece of solid space. First you trace out a line by the continuous motion of a point; that gives you a *singly* infinite number of points. Then you trace out a surface by the continuous motion of that line. This gives you a singly infinite number of such lines, and a *doubly* infinite number of points. Lastly, you trace out the solid by the continuous motion of the surface. The number of surfaces is then *singly infinite.* Of lines, there is an infinite number of such infinities;

that is, the number of lines is *doubly infinite.* Of points, there is an infinite number of double infinities; so that the number of points in a piece of solid space is three times as infinite as the number of points in a line. This number is called *triply infinite.*

In how many directions can I look without moving my head? If I put myself in front of a wall, every point on the surface of the wall is in a definite direction from my eye, and every direction leads to a definite point on the wall. Thus there are just as many directions as there are points on that surface; that is to say, a doubly infinite number of directions.

How many pairs of points are there on a piece of line? Let the first point move along the line; it will have a singly infinite number of positions. Select one of these, and then let the second point move along the line. It will have an infinite number of positions for each position of the other; thus altogether there will be a doubly infinite number of pairs. In the same way you will find that there is a triply infinite number of sets of three points, or of triads of points, on a piece of line.

All these things can be said in another way. Suppose that all you knew about a point was that it was on a certain line. That would not enable

you to identify the point; for you would not know which it was out of a singly infinite number. The point might vary among all the points on the line, and still fulfil the condition of being a point on the line. Still it could only vary in that one way. Such a point is said to have one variation. It is able to move about, but only on a fixed line. But to tell you that the point is on a certain surface would be to tell you less than this, for you would have a doubly infinite number of points to choose from. Suppose the surface traced out by the motion of a line; then the point might lie on any position of the line, and anywhere on the line. It could move along the line, and then the line might move along the surface. Such a point is said to have *two* variations. If now you are told merely that the point is in a certain region of solid space, you have a triply infinite number of points to choose from, and the point is said to have three variations. It may move along a line, then the line may move on a surface, and then the surface may move in space. Now the three kinds of room are distinguished by the number of dimensions that they have. Solid room has three dimensions, length, breadth, and thickness. Surface room has length and breadth, but no thickness. Line room has no breadth or thickness, but only length. So

we may now say that a point in space of three dimensions (solid room) has three variations ; a point in space of two dimensions (surface room) has two variations ; and a point in space of one dimension (line room) has one variation.

You must not suppose, however, that the idea of a number of variations is confined to single points. A pair of points on a line has two variations, for the two points may move independently. A direction in which you can look has two variations ; for it may take up a doubly infinite number of positions. And by-and-by we shall be able to see that a space has four variations—three of position and one of size. In order to identify a thing you must be told as many facts about it as it has variations. Thus a point on a line is identified if you know one fact about it, say the distance from one end of the line. But to identify a point on the earth's surface you must know two things ; for instance, the latitude and the longitude. And to identify a point in space you must know three things - the latitude, the longitude, and the height.

I dare say, now, that you are rather indignant at being kept so long hearing perfectly obvious remarks that are true of everything. You may think it is beneath the dignity of human nature to spend all this time in contemplating the size and

shape of a piece of wood. Very well; it is written in the fifteenth chapter of the Koran that when Adam was created all the angels were commanded to worship him. But Eblis, the chief of them, refused, saying, 'Far be it from me that am a pure spirit to worship a creature of clay.' And for this refusal he was shut out for ever from Paradise. Now the doom of Eblis awaits you if you fail to give due reverence to these little obvious everyday things—things that are true of every stone that lies on the pavement, of every drop of rain that falls from heaven, of every breath of air that fans you. Like him, you will find with astonishment that the creature of clay which you despise is the Lord of Nature and the Measure of all things, for in every speck of dust that falls lie hid the laws of the universe; and there is not an hour that passes in which you do not hold the Infinite in your hand.

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